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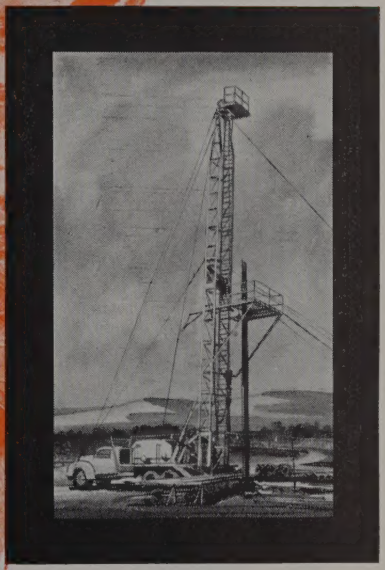

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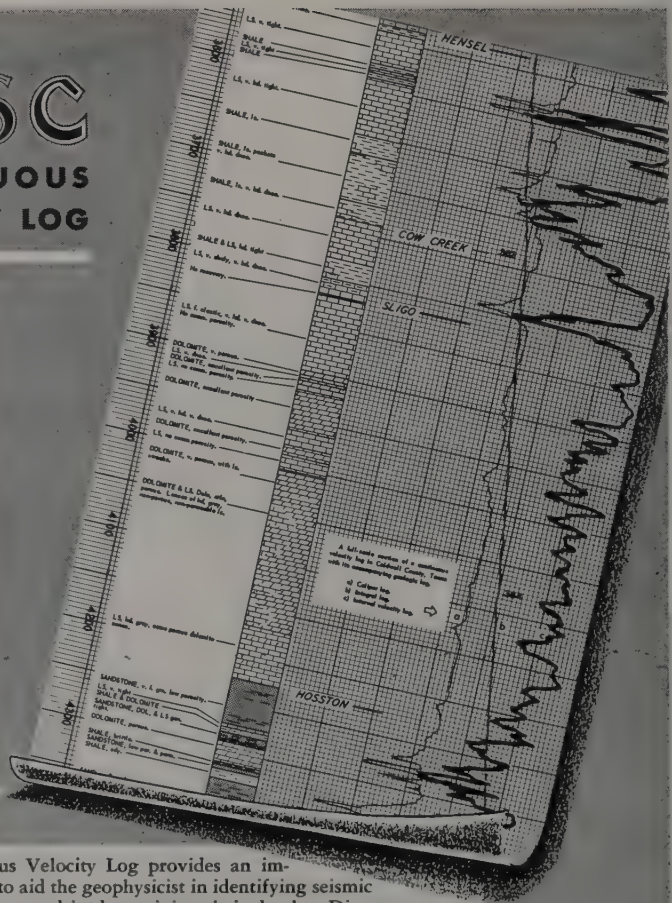

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EXAMPLES OF GEOLOGICAL AND GEOPHYSICAL CO-OPERATION IN PETROLEUM EXPLORATION

EDITOR'S FOREWORD

These examples of co-operation are collected to provide an interim report on progress toward an elusive goal. The small number of papers and scattered sampling of topics permit no exact generalization, but confirm specifically the increased powers of a joint effort.

In a hospitable environment, the methods of effecting co-operation differ according to the problem, and dominance is not an issue. In these papers co-operation has occurred by:

(1). interchanging techniques

(2). setting of boundary conditions

(3). supplying of areal detail

(4). determining the compatability of evidence

(5). determining the convergence of evidence

With one exception, the co-operation was effected in an office during or after the field work by operating rather than management personnel.

There has been no editorial prescription for the form of the papers except that they be case studies of co-operation.

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GEOLOGICAL AND GEOPHYSICAL CO-OPERATION

Ira H. Cram*

The publication by the Tulsa Geophysical Society of a number of papers on geological and geophysical cooperation is most constructive. Those of us who are close to geological and geophysical operations know that the rewards of cooperation are great. The literature on the subject, although not voluminous, is still sufficient to convince the uninitiated or doubting Thomas that the results of cooperation are gratifying. However, when the subject is so important the publication of additional papers on the subject is urgent.

In the early days of geophysics there was deliberate effort on the part of many geologists, geophysicists, and managements, to prevent cooperation between geologists and geophysicists. Many "good reasons" for promoting non-cooperation were advanced. There were certain geologists too lazy to learn the principles of the new tools; others fearing competition thought that non-cooperation was an effective roadblock to the progress of the newcomers. Certain geophysicists in their zeal to sell their new services felt that they could not admit the necessity of using geological help. And then there were managements who thought that the advantage lay in promoting rivalry rather than cooperation. These managements wanted "independent interpretations" of the problems at hand. Gradually it became obvious to both geologists and geophysicists that the various geophysical devices were in fact geological tools and that cooperation in the use of these tools improved the results. Management discovered that somebody had to interpret the "independent interpretations" and that either a geologist skilled in geophysics or a geophysicist skilled in geology was the best man to make that interpretation. Such skill could only be acquired through experience in both fields. Cooperation hastened the acquisition of the experience.

Actually it should have been apparent at the outset that the new geophysical devices were geological tools just as the petrographic microscope is a geological tool. By using the petrographic microscope the petrographer makes geological observations and measurements that would be difficult or impossible to make without this microscope. The geophysicist simply uses another set of tools to make other geological observations and measurements that are difficult or impossible to make without these new tools. Petrography had long been recognized as a branch of geology and nobody would consider promoting non-cooperation between petrographers and geologists. Hence, nobody should have given a second thought to the desirability of fostering non-cooperation between geologists and geophysicists.

In my approach to the subject of cooperation, I am inclined to stress the viewpoint of management. When petroleum was supposedly easier to find, management could perhaps afford the luxury of non-cooperation. As the search for petroleum becomes more frantic, complicated, and expensive, pressure to increase the effectiveness of the exploratory effort mounts. Any idea, however nebulous, on how to improve results is welcome today. Exploration besides being a venture in geology proves to be a venture in cooperation. It

*Senior Vice-President, Continental Oil Co., Houston, Texas.

has been a long time since a truly new geological tool was developed, but the rewards of cooperation among the various members of the exploratory team have proved to be so great that cooperation may well be the equivalent of a new geological tool.

In order to obtain maximum results the three main members of the exploratory organization—the land man, the geologist, the geophysicist—must work together as a team from the beginning to the end of the exploratory process. There are other people on the team such as the reservoir engineer, whose knowledge of reservoirs and their contents is invaluable. In fact, I doubt that anybody has either the knowledge or imagination to fully comprehend how many scientists and others are in effect on the exploratory team contributing daily to the success of the operations.

The exploratory program is the initial step in the exploratory process. The primary responsibility for organizing the program is perhaps the geologist's. The geologist with his broad knowledge of the geological picture should know better than the geophysicist the areas in which petroleum deposits are likely to exist. How to locate these deposits is a matter of cooperation between the geologist and geophysicist. Depending upon the geological setup, geophysical tools may or may not be necessary to locate certain deposits. However, the geophysicist with his knowledge of the geophysical devices will know better than the geologist the contributions that the geophysicist can make toward the solution of the various problems at hand. The land man through his knowledge of ownership and competitive forces should know better than either the geologist or the geophysicist if the anomalies to be discovered can be reduced to ownership. Hence, in the planning of an exploratory program, the knowledge and experience of all concerned are essential.

I am not advocating any particular method of cooperation between the geologist and geophysicist in carrying out the program. The method depends on company organization, the personalities of the people involved, and the nature of the geological and geophysical problems to be solved. Once the geologist fully realizes that all geophysical investigations reveal geologic data of significance and therefore demanding of his attention, he is mentally conditioned to cooperate. Once the geophysicist fully realizes that his information is useless until the geological significance of it has been appraised he also is mentally conditioned to cooperate. Geophysical investigations are meaningful only to the extent that they are translated into geology. In making this translation would anybody advocate that the geophysicist did not need the help of a geologist? It is certain that in modern exploration the last ounce of information whether obtained by geological or geophysical methods must be welded into a single interpretation. Whether the geologist or the geophysicist makes this "final" interpretation is immaterial so long as they cooperate in assembling and weighing all the evidence. Both the geologist and the geophysicist grow in stature through such cooperation and the natural outgrowth of this process of cooperation is the development of a new breed of earth

scientist capable of handling satisfactorily all data on the earth however acquired.

The primary responsibility of appraising the economic significance of the results of the geological and geophysical work is the geologist's. His broader knowledge of world-wide petroleum deposits qualifies him to take the lead in this appraisal. However, the geophysicist, particularly he who has had the broadening experience of cooperation with geologists, also can and does contribute to this appraisal.

I am tempted to forecast that the new breed of earth scientist referred to above will in the future be in the driver's seat of the exploratory machine. He may have progressed along either the geophysical or the geological route but the route he took is immaterial. It is only necessary that he shall have acquired a sound working knowledge of both what is ordinarily called geology and what is commonly known as geophysics.

INTERPRETATION OF A GEOPHYSICAL PROSPECT

by

R. W. Mossman*

ABSTRACT

In interpreting geophysical data it is essential to incorporate information on the geologic conditions characteristic of the area of the prospect. An analysis of the data on a purely geophysical basis can lead to very erroneous conclusions. As an illustration, a case history of a seismic prospect in a faulted area is presented, showing successive changes in the interpretation as additional geologic information is introduced into the evaluation. From an economically attractive graben, the interpretation is developed to show that a horst of even greater apparent potential is actually present, which is finally shown to be a very undesirable drilling site.

Exploration geophysics is the application of the principles of physics to evaluation of the structure of the earth's crust. Whether the phenomena measured are induced, as with seismic exploration, or are inherent, as with gravity and magnetics, the results observed vary with changes in the composition and attitude of the formation making up the lithosphere, and these variations permit interpretation of the structural conditions present. Unfortunately, because of the relatively limited range of expression of these changes, quite similar manifestations may result from quite dissimilar conditions. For this reason, no satisfactory interpretation of a geophysical investigation can be made except in relation to geologic conditions. As there is obtained more detailed knowledge of the geological factors, there will result more precise interpretation of the geophysical data.

For instance, in conducting a seismic survey, general knowledge of the geology is an obvious prerequisite to obtaining usable results. If the prospect contemplated is located in the Gulf Coast province, the interpretation procedures are at variance with those associated with a prospect in the more resistant beds of Oklahoma. These differences are caused by variation in the geologic conditions rather than any basic difference in seismic principles as applied in the two regions.

Consider the following specific case. A prospect was shot in an area in which two dominant, continuous reflections were recorded. Intermediate reflections were also observed but were not persistent over the entire prospect. The cross-section shown in Figure I represents the plotting of individual dips along one line of this prospect. Only those reflections which exhibited valid character were picked and plotted. Character correlations are indicated by the reflection designations α and β.

It is evident from even a cursory examination of Figure I that discontinuities are present in the shotpoint intervals C-D and F-G on the α horizon and in the interval C-G on the β horizon. The simplest geologic interpretation likely to be applied to this section would be as in Figure II, which depicts the

*Chief Geophysicist, Seismograph Service Corporation.

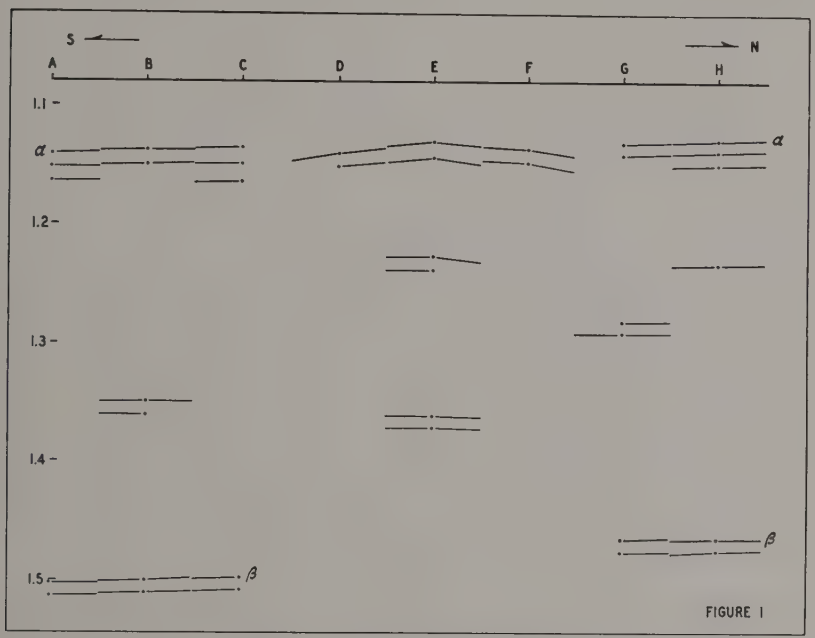


Figure 1.—N S Seismic Cross Section

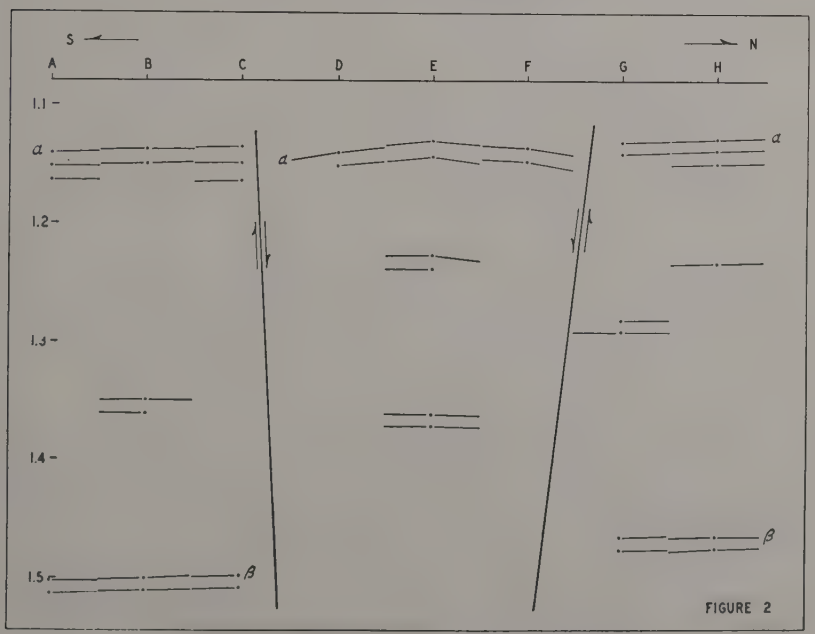


Figure 2.—Seismic cross section with interpreted graben

area between shotpoints C and G as a graben bounded by normal, high-angle faults. Since definite reversal of dip within the graben is indicated, the area becomes of economic interest.

Further exploration produced a contour interpretation on the horizon as shown in Figure III. From this interpretation it would appear that a location in the vicinity of Shotpoint E would be a good prospect for a test well.

Up to this point practically no geologic information had been applied to the interpretation of these data, beyond identifying the reflection voids as faulting. Let an additional item of information be added to the picture: the prospect is located in East Texas. Immediately, every geologist and geophysicist will take exception to the interpretation presented in Figure II because of knowledge of the expectable geologic conditions. The formations in this area are relatively incompetent as compared to strata in Central Oklahoma, for instance, and faulting in the area is recognized as generally having a low angle of dip: in the magnitude of 40 degrees. Other parameters of geologic and geophysical importance also become known when the area is identified. The principal producing zone is the Woodbine sand of Upper Cretaceous age, and reflections are usually obtained from the Taylor, the base of the Austin chalk, and from the Georgetown limestone. The Taylor reflecting horizon is about 1,300 feet above the Woodbine and the Georgetown reflection about 800 feet below that sand.

Some knowledge of velocity, a purely geophysical parameter, becomes available when location of the prospect is identified. Application of this velocity knowledge indicates that the shallow reflection, Horizon α, is probably representative of the Pecan Gap chalk of the Taylor, while the deeper reflection, Horizon β, is identified with the Georgetown limestone. Some of the intermediate, discontinuous data could represent the base of the Austin.

With this geological and geophysical information in mind, the fault pattern represented by the no-reflection zones can be redrawn as shown in Figure IV. In drawing this revised fault arrangement, it is necessary to make a further geologic assumption as to the relative age of the two faults, with the fault hading to the south presumed to be the younger.

Faulting of this nature is concomitant with general structural conditions in the area and appears reasonable. On this interpretation of Pecan Gap, α, horizon retains the same structural characteristics as in the first interpretation shown in Figure II. However, below the intersection of the faults, instead of a graben, a horst is present. This lends greater attraction to the prospect, and suggests that a highly profitable feature might be present.

A contour map on the Georgetown, β, horizon was prepared in depths converted from the time data using the average velocity pertinent to the area and the reflection. This permitted introduction of another geologic parameter to the interpretation: the relationship between the seismic data and formation tops observed in the wells or dry holes. The contour interpretation of these depth data, shown in Figure V, indicates excellent ties with dry holes 1 and 2. The shallow Georgetown top reported in dry hole 3 suggests that the partial reflection observed at a time of about 1,360 milliseconds on the

FIGURE 3

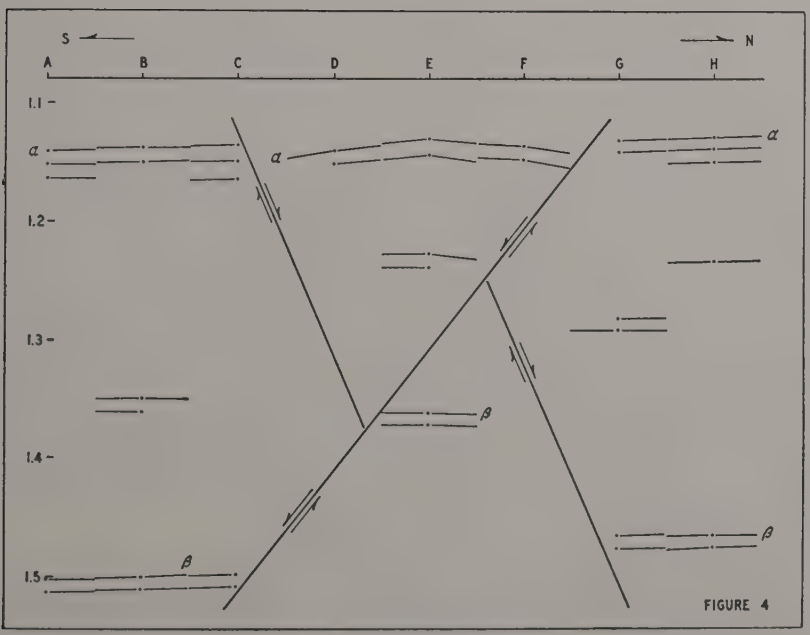


FIGURE 4

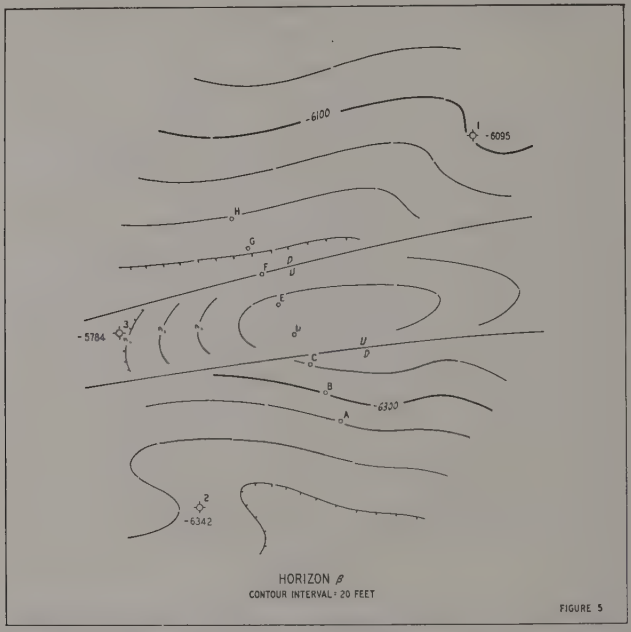


Figure 5.—Contour map of horst interpretation at horizon beta

record from shotpoint E| might be the β event in the horst block. Unfortunately, no direct tie with dry hole 3 could be obtained. Re-examination of the records did suggest that such a correlation and identification for this partial event was entirely possible.

At this point the investigation might well have been considered to be complete, and from the standpoint of geophysics alone, little additional information on the prospect could be offered, since the surface coverage obtained appeared to be as comprehensive as economic considerations warranted.

However, there was still geological information available which could be incorporated into the investigation. The electric resistivity and self-potential logs of the dry holes were re-examined in the light of the proposed fault pattern, thus bringing another application of geophysics to bear on the geologic evaluation of the prospect. The electric log from dry hole 3 recorded a probable fault about 800 feet above the Georgetown, further confirming the validity of the fault pattern as postulated.

The interpretation still could not be considered to be complete from the standpoint of presenting a drillable prospect, since the horizons mapped are not entirely conformable to the Woodbine. And the Woodbine is not only

the most prominent producing zone in the area but is also the only sand offering any real assurance of containing oil when structural or stratigraphic features are suitable. Therefore, a theoretical position of the Woodbine was drawn on the cross-section, as shown in Figure VI. In drawing in this sand, the question arose as to where it was located in the zone between the faults. If the tentative identification of the position of Horizon β, Georgetown, is correct at Shotpoint E, the Woodbine would be well above the intersection of the faults. However, projecting downward from the Pecan Gap which appeared to be reliably identified, the Woodbine would be below the fault intersection. Apparently, therefore, the sand is entirely absent in the fault zone.

Further examination of the electric log in dry hole 3 showed no sand development in the zone where the Woodbine should be encountered, and additionally indicated a considerable shortening of section between the Georgetown and Taylor.

A further, simple experiment was made which confirmed that a fault pattern, such as that revealed by the investigation, could completely eliminate a portion of the columnar section. A restored cross-section was drawn, with no faulting present. This section was then cut along the plane of the older fault and the section displaced along this cleavage by the amount of throw indicated by the Georgetown data at Shotpoints E and G. The section was then united and a second cut made along the younger fault plane. The two

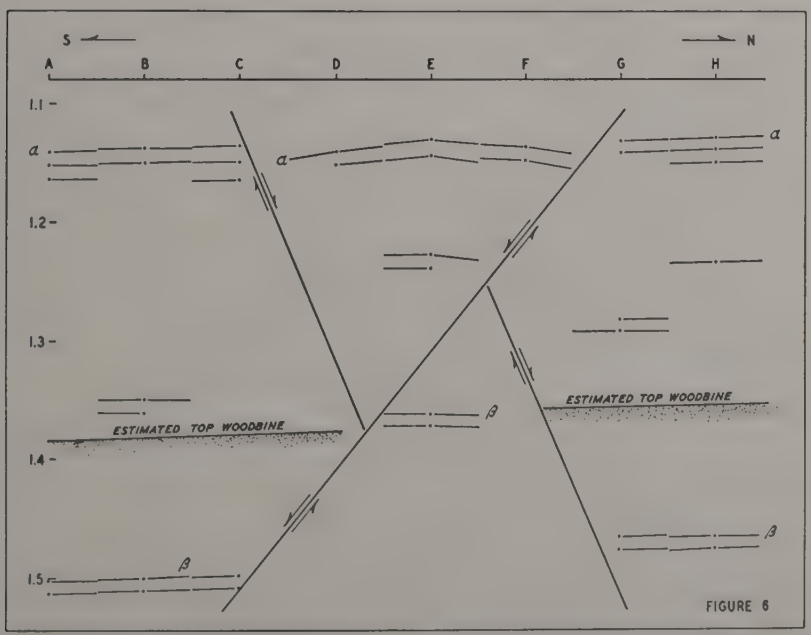


Figure 6.—Seismic cross section with inferred position of woodbine sand

portions were then shifted to place the Georgetown, β, horizon at its present relative position north and south of the fault zone. The Woodbine no longer was present between the faults. No allowance could be made in this experiment for the differential throw of the faults with change in depth, but the result was still conclusive enough to account for the removal of the sand from within the zone of faulting.

Interesting corollary information was obtained from this experiment, bearing on the dynamics involved in this system of faults. The down-to-the-north older fault appeared as a compressional fracture: the section was compressed along its horizontal axis. The younger, down-to-the-south fault was of tensional nature, elongating the section along its horizontal axis. This is in accord with the generally accepted dynamics of the Gulf Coast province in which down-to-the-coast faults are considered to be tensional, relief faults.

While in this instance, the combined application of geology and geophysics to the interpretational problem resulted in condemning the prospect, at least for potential Woodbine production, a considerable expenditure for leasing and drilling was averted. Had only a purely geophysical interpretation been presented, or at best, only general geologic considerations been applied, another dry hole might have been drilled and classified as a geophysical failure.

A GEOLOGICAL-GEOPHYSICAL PROBLEM IN TILLMAN COUNTY, OKLAHOMA

Joseph L. Marucheck and Charles H. Glidden*

Introduction

A subsurface geologic study was made by Union Oil Company of California of southern Tillman County, Oklahoma, and most of Wichita and Wilbarger Counties, Texas. The wealth of available data on the Texas side of the Red River gave indications of the lensing nature of Cisco sands, the limestone build-ups within the Canyon zone, and the manner in which the Strawn overlaps all older horizons. Well data on the Oklahoma side of the river indicated that a thick Mississippian section is truncated in a northwest-southeast line across Tillman County. Sample examination indicated that the Hunton, Viola and Simpson sections could not be considered Class A objectives; however, the Arbuckle was definitely a potential producer, both on structural highs and in porosity traps.

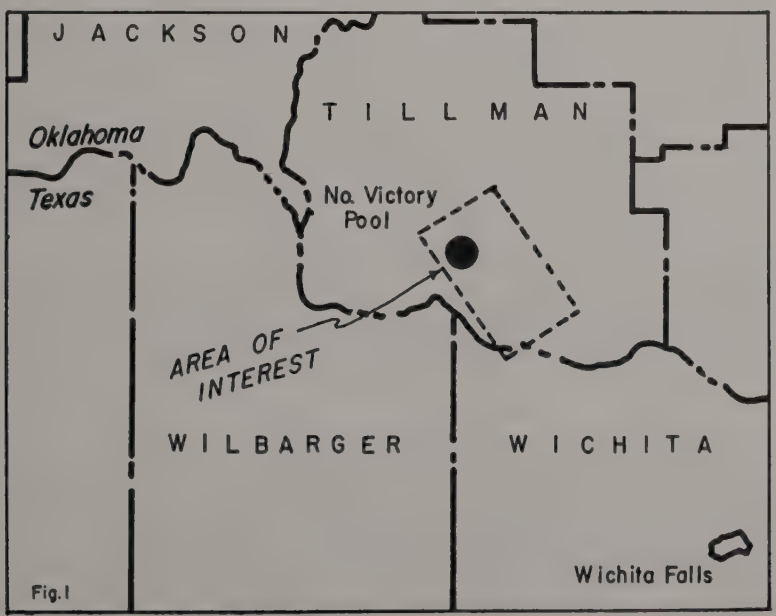


Fig. 1

*The writers wish to express their appreciation to Mr. L. E. Fitts, Jr., Union Oil Company of California, and to Mr. S. J. Allen, United Geophysical Corporation for permission to publish this paper.

Optimistic contouring on rather meager well data indicated that trending northwest-southeast across southeastern Tillman County, between the Frederick Field in Tillman County, Oklahoma, and the northwest extension of Burkburnett in Wichita County, Texas, was a ridge or saddle with several hundred feet of relief on the deeper horizons. Apparently, this ridge was a spur off the Red River uplift.

Due to the sparsity of deep wells along this ridge, it was felt that there was ample room for yet undiscovered closed structures, faults, and stratigraphic traps over and around noses.

Subsurface studies were followed up with a reconnaissance type seismograph survey of a portion of southeastern Tillman County, Oklahoma. The primary purpose of this survey was to confirm and delineate the structural ridge indicated from the well data; also, because of suspected thickness variations within the section (therefore possible stratigraphic traps), it was planned as part of the geophysical program to investigate and evaluate the adaptability of "high fidelity" seismograph recording to the area.

The program, which began in January, 1953, employed a United Geophysical Corporation seismograph party equipped with instruments designed for wide frequency band recording. The general field procedures including permitting, surveying, drilling and shooting varied little from standard methods. The recording procedures and techniques of the crew were somewhat different due to the partly experimental nature of the program.

Recording Procedure

Initial shooting in the area revealed that relatively wide range of reflection frequencies could be expected. Furthermore, the extraneous noise level was comparatively low; thus, it was considered probable that a wide frequency band could be satisfactorily recorded and interpreted with no appreciable difficulty due to a high "noise to signal" ratio.

Accordingly, for essentially the entire prospect, minimum filtering was employed. The only conditions encountered where the noise level was sufficiently high to require selective filtering were during parts of a few very windy days, and in some isolated locations immediately adjacent to the Red River where considerable thicknesses of unconsolidated wind blown sand had accumulated.

The initial experimental shooting of the prospect was effected with special high fidelity recording equipment. During this period of experimentation it was found that the maximum reflection frequency range that could be expected from the shallowest mappable horizons to the deepest Arbuckle reflections would not exceed 100 to 120 cycles per second at the high end of the reflection spectrum and at the low end, would not fall below 20 to 25 cycles per second.

Based primarily on these observations, the United type 1-32 amplifier was selected for the survey. This amplifier, by itself, passes a very wide range of frequencies. In its widest filter combination the response is flat from 10

to 400 cycles per second, and, at -1 D.B. or -10%, the range is extended to seven cycles per second and 500 cycles per second. For the range of seismic frequencies this can accurately be termed high fidelity. In actual field operations the falling off of over-all response at high and low frequencies was sharper than that of the amplifier alone, being controlled by the geophone type on the low end and by the galvanometer type on the high end.

The filter characteristic for the over-all response of the recording system, as used by this survey, reaches maximum gain from 30 to 50 cycles per second and passes frequencies from 15 to 125 cycles per second at -6 D.B. This filter setting (1-9) was used for the entire survey, with the only exceptions being for the strong wind and unconsolidated sand conditions mentioned above. These conditions were largely compensated for through selective filtering. (For certain phases of the earlier experimental shooting the over-all response of the recording system was considerably expanded through use of pressure type geophones and high frequency galvanometers.)

The 1-32 type amplifier, in addition to its broad frequency response characteristics, has a relatively slow acting AVC control system designed to preserve, as much as possible, all of the information contained in the envelope of the ground signal. The amplifier is also provided with a signal handling capacity for peak excursions several times above average AVC level.

Continuous profiling, employing a shot point interval of 1,320 feet, was used during the reconnaissance phase of the operation. Subsequent detailing within certain areas required a 1,000-foot shot point interval. Normally, 24 traces employing six geophones per trace were recorded. The average shot hole depth for the survey was 120 feet, and average charge size was about 15 pounds. The seismograms were recorded with a comparatively fast camera speed of 25 inches per second in order to allow easier detailed studies of the records.

The vertical cross sections were constructed by plotting all reflections in depth. The velocity function used was based on a velocity survey of a well adjacent to the area surveyed. In any area where reflections with appreciable dip were noted, all events were migrated. All reflections were corrected to a flat, or horizontal, datum.

A total time of approximately five months was required to complete the survey; operations were concluded in September, 1953.

Interpretation

All available data were used in preparing the final interpretation to arrive at what was considered the most reasonable subsurface pictures. The majority of the wells in the area proved to be Canyon tests; however, a sufficient number penetrated the Arbuckle to give reasonable control for the Arbuckle map.

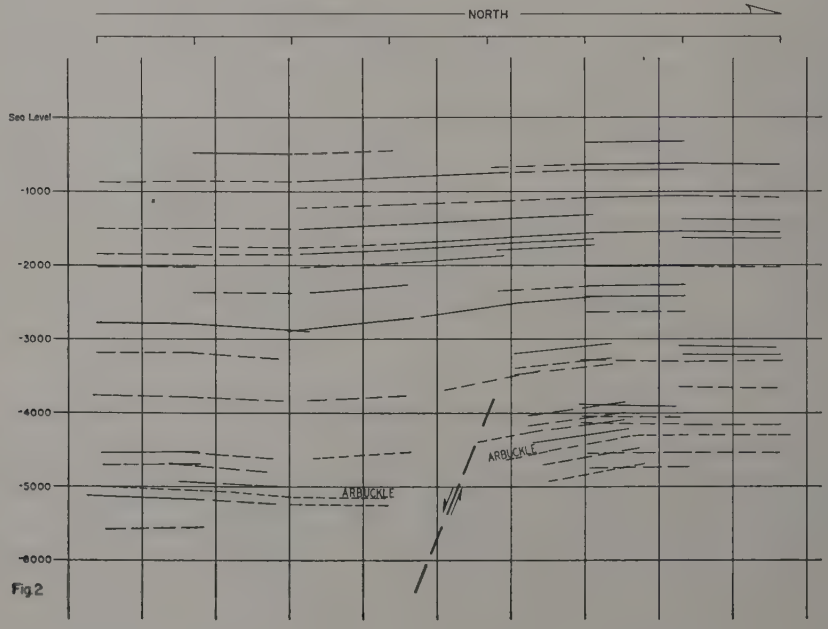
Formation tops from all wells in the area were furnished to the seismologist as an aid toward a more comprehensive interpretation of the records

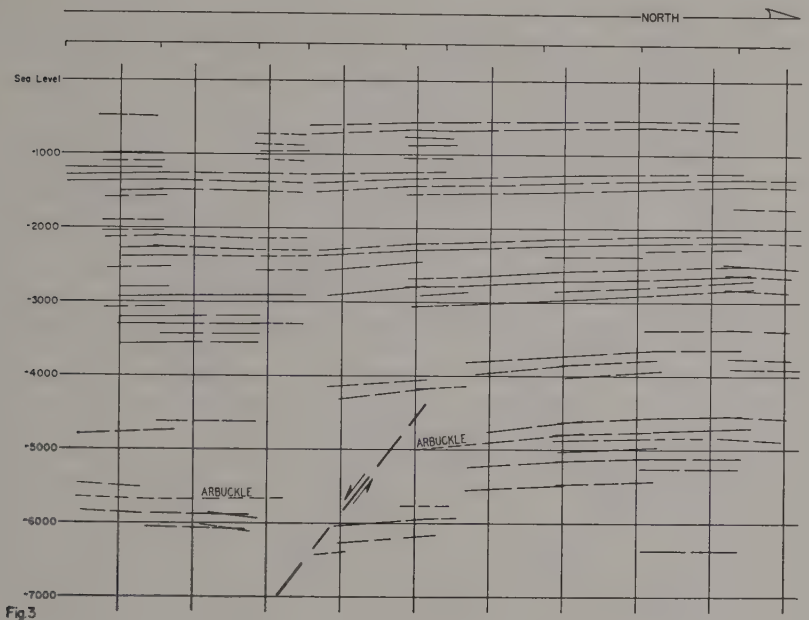
and fullest development of the cross sections. All reflected events were picked and plotted regardless of their degree of conformity with, or depth in, the section. Primary emphasis was placed on reflection character studies; the broad band width of recorded energy permitted extraordinary character expression of many reflecting horizons.

The most persistent reflection on the records plotted 435 feet below the top of the Canyon. This horizon was mapped over an area of sixty square miles and tied to all known Canyon tops in drilled wells with an error of tie of less than plus or minus 20 feet. This seemed to indicate no velocity gradient of an abrupt nature to the top of the Canyon.

The construction of an Arbuckle map proved to be considerably more difficult and somewhat less accurate than the Canyon map. A number of factors seem to be involved; namely, a change in velocity due to the facies changes in the Canyon section, thickening in the Strawn section, low frequency and often discontinuous reflecting horizons from the Arbuckle, and faulting.

The faulting was identified from seismic data. All geologic control for the Arbuckle is on the high side of the fault. There are, unfortunately, no wells drilled on the downthrown side to aid in determining the extent of the fault displacement. The following cross sections, chosen from those that cross the fault (Fig 2-4), will illustrate its presence and possible throw. (Since all sections intersect the fault obliquely, the fault details are somewhat distorted and its exact location, somewhat doubtful.) The character and continuity of the Arbuckle reflections are such that they often cannot be correlated across the fault zone.




NORTH
Sea Level
-1000
-2000
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ARBUCKLE
ARBUCKLE

Fig.3

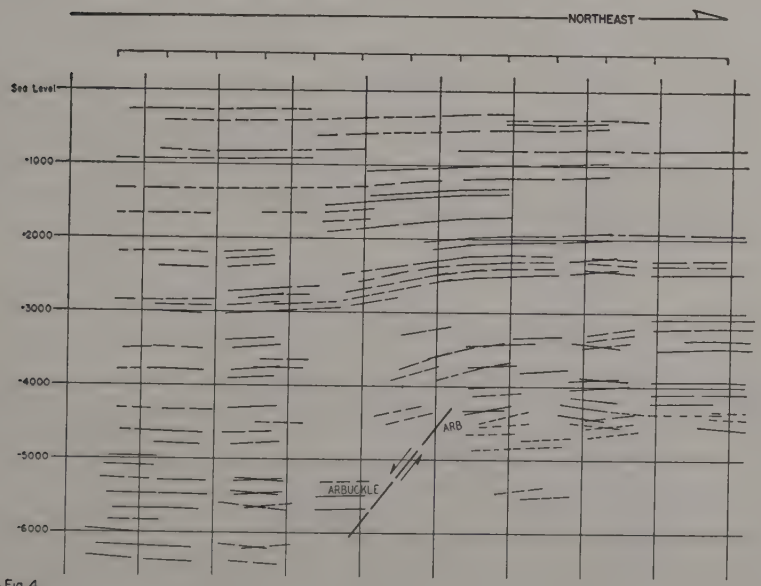

NORTHEAST
Sea Level
-1000
-2000
-3000
-4000
-5000
-6000
ARB
ARBUCKLE

Fig 4

Common indications of faulting such as draping of the upper beds over the fault, discontinuity of reflecting horizons, zones of reflection distortion, and the presence of a thickened section on the downthrown side of the fault, are all evident on the included cross sections.

Results

The Canyon seismic map confirmed the presence of a northwest trending ridge through the area. Where the Arbuckle data are fair to good a strong similarity is noted between the Canyon and Arbuckle horizons with, however, the Arbuckle indicating greater structural development. From several anomalies mapped on the Canyon horizon, location was selected for the Union Emenhiser No. 1 in the NE NE NE section 23-3s-17w. The Canyon was topped very close to the elevation shown on the seismic map. The nearest Canyon test was two miles to the west. The well continued into the Arbuckle which was encountered somewhat lower than anticipated. Shows were encountered in a lower Cisco sand, the lower Strawn conglomerate, and the Chimney Hill member of the Hunton.

On the basis of a dipmeter survey and data from an additional seismic line from the northeast to the southwest corner of section 23-3s-17w, it was determined that the Canyon would be slightly higher and the Arbuckle possibly 150 feet higher at a location about one-half mile to the southwest. The Emenhiser No. 2 was drilled in the NW SE NE of Section 23 and found production in a basal Cisco sand. The well was stopped in the pay sand and did not test the Canyon. The Emenhiser No. 3 was then drilled in the NE SE NE of section 23. It found the same productive sand in the basal Cisco and confirmed the Canyon and Arbuckle tops as predicted from the seismic data.

This field is now in the development stage. Additional wells will be required to determine its extent, its sand conditions, and its final relation to the seismic data map. The nature of the Cisco and Strawn sands presents additional possibilities of oil entrapment, but the true significance of the southeast trending fault and its relationship to oil potentialities must await additional seismic and drilling operations.

Geological - Geophysical Coordination

The geologist making the subsurface investigation maintained close contact with the party chief and seismologist on the crew. The geophysical personnel were thoroughly briefed on the regional geology and, as much as possible, on the detailed geology of the specific area of interest. Copies of correlations of all available electric logs were furnished to the seismologist. About once a week meetings were arranged between the seismologist and geologist to review and discuss the results of the seismic shooting. In all instances where the shooting was adjacent to wells, an attempt was made to correlate, as closely as possible, well information to seismic data. All program was planned at the time of these weekly discussions.

The seismologist endeavored to keep the geologist adequately informed, at all times, of his results so that program additions, or changes, could be made without delay.

The results of this close technical association between the geological and geophysical personnel were: (1) increased confidence by the geological department in the seismic interpretation, (2) programming with maximum efficiency, and (3) valuable assistance to the seismologist, through frequent meetings, in developing a geologically complete final interpretation.

PERMIAN SALT PROBLEM - WESTERN KANSAS

D. F. Moore*

Introduction

During 1946-47, the Stanolind Oil and Gas Company concerned itself with rather extensive Core Drill and Geophysical operations in southwestern Kansas and the Panhandle of Oklahoma. The findings of this exploration were enlightening from the standpoint of shallow subsurface conditions and the effect of these conditions on seismic velocities.** Core holes to the Base of the Blaine indicated one area of considerable lateral extent in which several hundred feet of relief were noted. Abrupt increases in seismic velocity over this area suggested relief of like proportion. Slight en echelon faulting was noted on one edge of the anomalous area which Stanolind wished to check with depth. Subsequent core holes taken across this line of faulting and drilled to the Cimarron Anhydrite suggested only normal regional dip. Actual cores and samples taken from these core holes indicated as much as 350 feet of salt occurring immediately below the Blaine. Subsequently, it was learned that the salt area was coincident with the area in which 350 feet of divergence between the Blaine and the Cimarron occurred, and also coincident with the area in which abrupt seismic velocity change occurred. Evidences of solution and collapse had long been noted in western Kansas, some of which were still apparent on the surface in the form of sinks and faults. Others were suspected when abnormally long Cretaceous sand sections were encountered. Geologic cross-sections further suggested that solution of shallow salt entities had been initiated following the end of the Permian.

Stratigraphy

Primarily this paper concerns the stratigraphy of the Nippewalla and Upper Sumner Groups of the Leonardian Series of the Permian System. Of the total 2600 feet of Permian represented in the Hugoton Gas Field, the section with which we are here concerned involves the upper 700 feet. Salt development occurs in the shale and sandstone interval below the Blaine formation and above the Cimarron (Stone Corral) Anhydrite. This interval is represented by the Flowerpot shale; Cedar Hills sandstone, Salt Plaine and Harper formation; all of which represent a rather continuous succession of red and gray silty shales with thin discontinuous beds of salt, sand and gypsum. The Cimarron is represented by two thin Anhydrite beds separated by some 50 to 60 feet of amorphous salt. The thickness of the latter salt entity does not vary appreciably over the entire Hugoton Gas Field area.***

*D. F. Moore, Consulting Petroleum Geologist, formerly employed by the Stanolind Oil and Gas Co., Tulsa, Oklahoma.

**M. B. Widess, "Salt Solution, A Seismic Velocity Problem in Western Anadarko Basin, Kansas-Oklahoma-Texas", GEOPHYSICS, XVII, July, 1952, p. 481.

***D. F. Moore, Occurrence of Permian Salt—Western Kansas, presented at Regional A. A. P. G. meeting Sept. 30-Oct. 2, 1954, Wichita, Kansas.

Geography

Two distinct areas of Blaine salt occurrence exist in southwestern Kansas, northern Oklahoma, and a portion of the Texas Panhandle. Geographically, the northern-most area occurs 1200 feet from the surface in Wallace, Logan, Greeley, Wichita, Scott, Hamilton, Kearny, Stanton and Grant counties; an area embracing nearly 3800 square miles. This area was readily discernible upon examination of electric logs and cores taken in the area. Another area southeast therefrom embraces more than 7,000 square miles in Ford, Edwards, Kiowa, Commanche, Meade, and Clark counties (Kansas); Beaver, Harper, Woods, Ellis, Woodward counties in Oklahoma, and a portion of the Texas Panhandle. The southern extremity of the latter area was not determined. The intervening northwest-southeast straight-line distance between the two salt areas is approximately 70 miles, and represents an area of more than 7,000 square miles in which no salt occurs. Presence of a large salt entity in the southernmost area was discovertd following extensive core drill and geophysical work conducted by Stanolind during 1946-47.

Discussion of Blaine Salt

Using the Base of the Blaine and the Base of the Cimarron as "markers", an Isopach map was constructed. The divergence of this interval was found to be proportional to the thickness of salt present.

Surface depressions, sinks, and basins are sharply localized east of the line of greatest divergence in central Meade county. Frye, (1942 & 1950)* discusses the Crooked Creek and Fowler en echelon faults, which, after inspection, were found to lie parallel and along the line of greatest divergence in the Blaine-Cimarron interval. The eastern sides of these faults are upthrown. The faults cut Pliocene - Pleistocene sediments and apparently cut a portion of the Permian above the Cimarron. The Cimarron however, maintains normal southeast dip across the fault lines. The pronounced surface expressions have heretofore prompted recognition by Haworth (1896); Johnson (1901); Smith (1940)**; and Frye (1942 & 1950). The scope of this paper does not permit discussion of their somewhat varied hypotheses, however, Frye's interpretations of topography, stratigraphy, and hydrology lend themselves well to solution-collapse phenomena.

Shallow Cretaceous subsurface study has indicated abnormally thick development of sands and alluvial deposits in and adjacent to the salt occurrence in the northern, or Hugoton area. Salt solution and collapse of the associated beds before Cretaceous deposition would adequately account for abnormal thicknesses of the younger Cretaceous beds. The relative absence of abnormally thick sections above early Cretaceous indicates that active solution and collapse was curtailed in the northern salt area soon after Dakota deposition. Though detailed subsurface information in the "no salt" area is not presently available, it is believed that the present position of the two salt bodies approximates their position after Cretaceous deposition. Subsequent Quaternary deposits could therefore have masked topographic sinks and troughs caused by collapse of the Pre-Cretaceous beds.

*J. C. Frye & S. L. Schoff, "Deep-Seated Solution in the Meade Basin and Vicinity, Kansas and Oklahoma", AMERICAN GEOPHY. UNION TRANSACTIONS, 1942, Part 1, pp. 35-39. J. C. Frye, "Origin of Kansas Great Plains Depressions", State Geol. Survey of Kansas, Bull. 86, Part 1, 1950.

**H. T. U. Smith, "Geologic Studies in Southwestern Kansas", Bull. Univ. Kans., Bull. 34, Vol. 41, No. 18, Sept. 1940.

The anomalous attitude of the Blaine where major salt exists suggests the pre-existence of a continuous and much larger salt entity. I submit therefore, that the two presently isolated salt areas were at one time connected. The attitude of the initial salt deposit followed, as expected, the strike of the northwest extension of the Anadarko Basin. Unconformities occurred following Blaine deposition and at the close of Permian deposition which may have supplied the ground waters necessary to initiate salt solution. Probable charge areas existed in eastern Colorado along the eastern edge of the Las Animas Arch and in northern Kansas at the northernmost reaches of the Anadarko Basin.

Despite the major unconformity which occurred at the close of the Permian, the Jurassic and Triassic deposits were quite similar to those of the Upper Permian or Guadalupian Series. Only 40 to 50 feet of Jurassic-Triassic sands and siltstones were deposited in southwestern Kansas, the major deposition occurring in northwestern Kansas, southeastern Nebraska, and northeastern Colorado. The Pre-Cretaceous dip of the Cimarron was southward into the synclinal axis of the Anadarko Basin. During the Cretaceous, basement readjustment occurred such as to cause broad regional tilting toward the Denver or Julesberg Basin to the north. The resultant dip of the Cimarron was somewhat north of east. This attitude presently persists northward into southwestern Nebraska and eastern Colorado. The initial salt body probably had, before the Cretaceous, been subjected to rather vigorous solution activity. However, the radical change from south to north dip in the Hugoton area during the Cretaceous may have retarded if not discontinued this activity and would account for the undisturbed salt entity in the Hugoton area. Regionally, we note that the original southeast dip on the Cimarron was not appreciably disturbed southeast of the Hugoton Gas Field. The direction of ground water flow therefore has probably persisted in a southeasterly direction. The end result was the continuation of solution and collapse in the southern area (Meade county), with the subsequent slow retreat of this salt body.

Cross-Sections

A series of geologic and electric log cross-sections were constructed using several datum planes in order to reconstruct the conditions that prevailed during salt deposition, and subsequent geologic phenomena which was responsible for the present attitude of the two salt entities. In essence, the Blaine formation illustrated an anomalous condition when a salt area was entered, whereas the Cimarron, only a few hundred feet lower in the section, expressed only regional dip. Divergence of the Blaine-Cimarron interval occurred abruptly in every instance within a lateral distance of two to four miles with as much as 100 to 350 feet of thickening apparent.

Sections were constructed in areas wherein no salt occurred. The interval between the Blaine and the Cimarron thinned and thickened erratically, some-

times as much as 60 feet. Normally, in an area of mild folding, about the only factors that could cause this interval between two "distinct markers" to change are: erosional unconformity between the markers, which fact can probably be eliminated in this area; unusual deposition such as reefs, or the filling of low troughs. This factor can be eliminated as the Blaine does not show any unusual thickening. The remaining factor would be the solution on the salt section after deposition of the markers, and the collapse of the associated beds.

Recently, 195 feet of salt section was diamond cored in a well drilled by Stanolind in the Hugoton salt area. Of the 195 feet presumed to be nearly pure salt by electric log interpretation, 41% was found to be impurities. With the knowledge that the salt is impure to this degree we may reasonably explain an increased thickness of shaley section where the salt is absent. These impurities, not represented by uniform bedding planes or uniform deposition, would be expected to vary in quantity over a local or broad area, depending on the uniformity and extent of the original salt beds. Subsequently, we expected and found some variation in the Base-Blaine-Top Cimarron interval where the salt had been removed.

Summary & Conclusions

Through the use of presently available information, I have assembled certain related data which establish the existence of solution and collapse phenomena in two isolated Blaine salt areas.

Solution and collapse are believed to have prevailed since late Permian time over the entire area. Structural movement and change of dip during Cretaceous deposition are believed to have somewhat isolated a portion of the original salt entity. Minor basement readjustments that have since occurred have not been of great enough magnitude to have appreciably altered the rate of solution. Lithology variations in the Base Blaine-Cimarron interval are believed to be in part responsible for the localization of sinks and troughs in the southern area (Meade county, etc.). Prevailing charge areas in conjunction with the lower elevations of the North Canadian and Cimarron watersheds (Oklahoma); and the regional dip and outcrop positions of the Blaine and Cimarron formations, provide an entrance and outlet for the ground waters that effect solution phenomena in the southeastern salt area.

We cannot satisfactorily predict local areas in which salt thicknesses are constant because of: the nature and localization of solution and collapse phenomena, the lithology variation of the ground water carrier, and the local affect that ground water has had on the present salt bed.

CROSS-SECTION INTERPRETATION IN THE ANADARKO BASIN

J. E. Finley and G. W. Fenner*

This paper presents seismic and geologic cross-sections interpreting the geological complexities of the Wichita Mt. Front, and the associated southern limit of the Anadarko Basin. In our opinion, this interpretation offers the most logical solution when all available data, both geological and geophysical, are coordinated with freedom from professional prejudice.

Two superimposed, well-defined, major orogenies, each characterized by accelerated movement, rather than singular upheavals, are recognized at the southern limit of the basin. These movements have created a maze of faulted and eroded structures, and have effected great variety in the type of possible oil traps. The first orogeny occurred in Lower Pennsylvanian time, forming the Wichita Mts. on the border of a large geosyncline, which had developed from the Cambrian to the close of Springer time. This movement exposed the Pre-Pennsylvanian and Lower Pennsylvanian beds to erosion by its distinctive block faulting; while, immediately to the north, the Anadarko Basin continued filling with sediments from this immense new source. From the close of this activity to the advent of Upper Pennsylvanian time, little is known; but it is believed that this was a period of stability with only minor changes in sedimentation. Following the close of late Hoxbar time, the second of these major upheavals occurred, creating many additional structures, as well as reactivating those belonging to the Wichita movement; folding, faulting, and basinward thrusting are known. Small hogbacks, occurring largely near the Wichita Mts. in resistant formations, are associated with this movement; these were later onlapped by Cisco, Pontotoc, and Permian sediments.

Obviously, from the distortion suggested above, a contour map of one or many horizons would fail to truly represent the potential oil-bearing structures. Therefore, the technique best suited for their interpretation is the preparation of geological-geophysical cross-sections. To prepare these, it is required that all seismic data be displaced (migrated) to its true position and the dips entered in depths and degrees rather than time. It was found that if a one to one relationship between cross-sections and the original map were maintained, then the sections, when completed, could be so placed upon the maps as to represent true position and perspective. The sections shown are typical of a series of cross-sections of the subject area. It is evident that any attempt to correlate the geophysical data shown here, without the use of geological control, would be futile; as would be such an attempt with only geological data.

Figure 1 is a northeast-southwest cross-section of the geophysical data from Line 1. There appears to be a little correlative information present, except for a shallow unconformity across the entire section at a depth of about 2000 feet. Below this, a thick section appears to diverge northeast from shotpoint B. Southwest of Shotpoint B, a sharp reversal is apparent; but the cause of this reversal is evident only after an addition of the subsurface data. Figure 2, combining seismic and geologic data shows a logical interpretation. The

*Continental Oil Co., Ponca City, Oklahoma

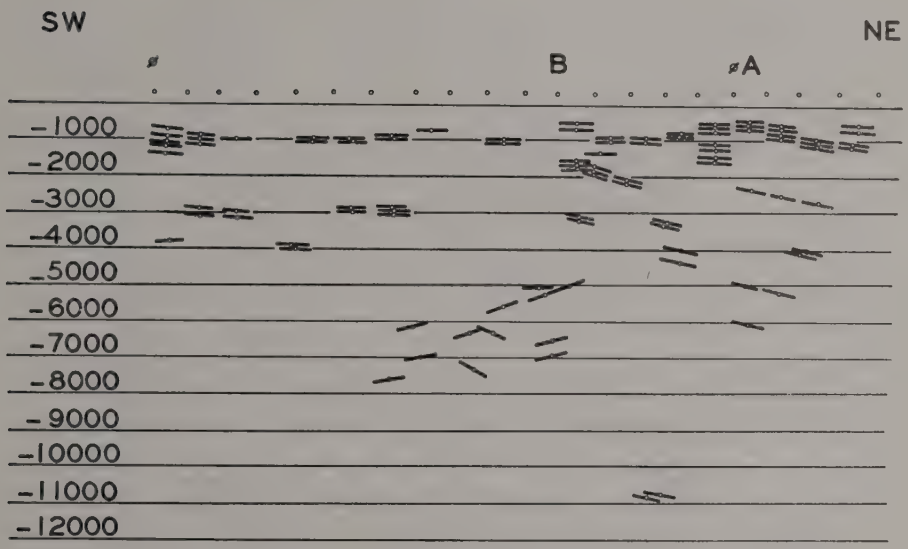


Fig. 1. Seismic cross-section SW - NE Line 1.

sharp reversal resulted from a thrust fault; this being fairly well established by subsurface control immediately northwest of this lime. A well drilled at shotpoint A bottomed in the Hoxbar sediments, revealing a thick basin section. Subsequent tops in this section were established by applying known maximum thicknesses to the remaining Pennsylvanian members.

The similarity of Figure 3, Line 2, to Figure 1 can be noted. The shallow unconformity, the steeply dipping deeper section and the obvious lack of data southwest of shotpoint C are clearly indicated. Again, it is relatively easy to explain these seismic observations by the addition of known subsurface conditions as shown in Figure 4. The area void of reflections is shown to be a faulted, recumbent fold. A preserved hogback of Pennsylvanian sediments is shown in the form of an eroded fault scarp, which is considerably shallower and more acute than it appeared on Figure 2. By projecting the beds in accordance with the indicated dip, it is again possible to show prospective Lower Pennsylvanian beds within reach of the drill.

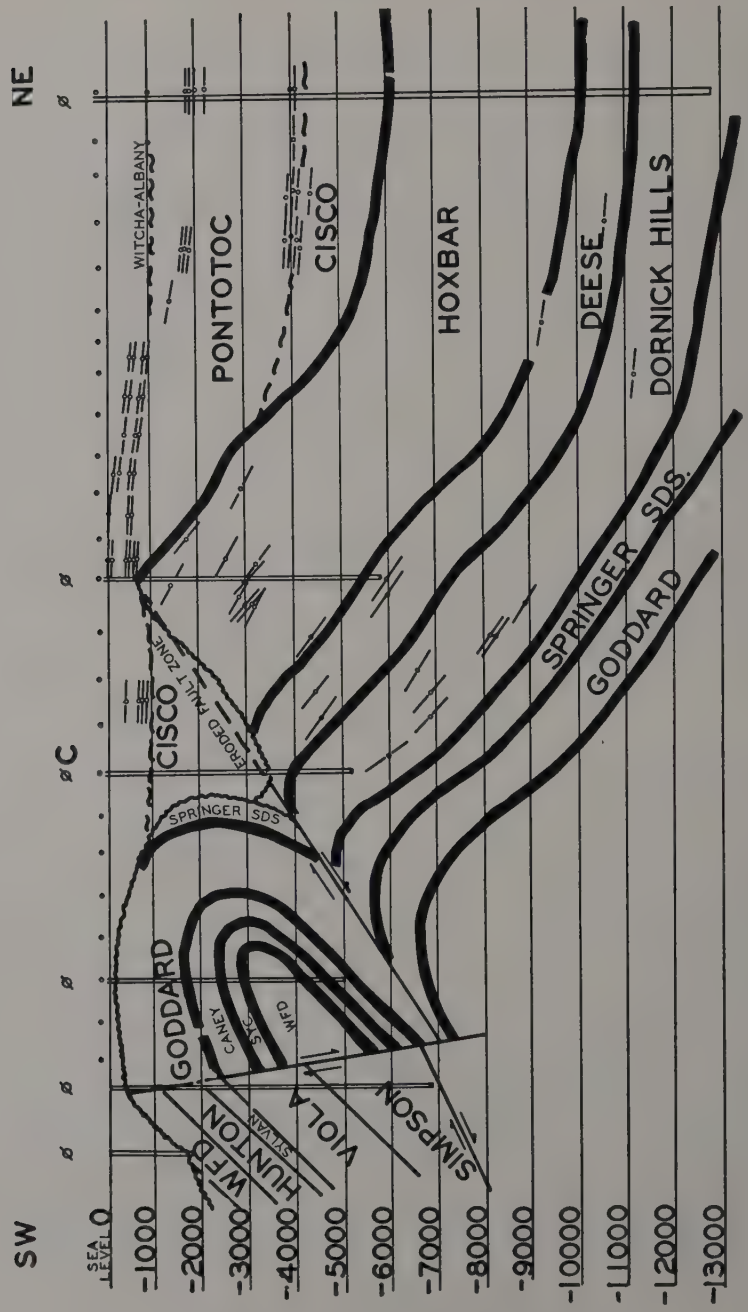


Fig. 2. Interpretation of seismic cross-section SW - NE Line 1.

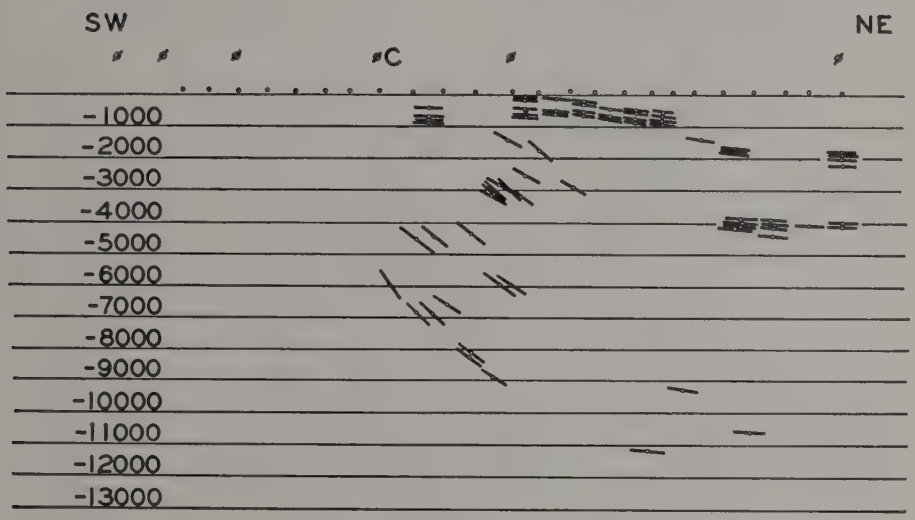


Fig. 3. Seismic cross-section SW - NE Line 2.

An interesting comparison can be made between figures 2 and 4. The eroded fault scarp is more deeply buried in Figure 4, and yet Figure 2 indicates that at this point it was subjected to greater erosion. Apparently, the cross-section at 2 was at one time higher than that at 4. Subsequent folding and regional tilt has reversed these conditions. The comparison of seismic dips on these two sections reveals an increase in the amount of dip in the Pennsylvanian section on Figure 4 suggesting an increase in the degree of folding to the north.

The techniques employed on these sections are certainly not so elaborate as to confine their use to problems of special concern. On the contrary, they were designed and used, under normal operating conditions, to meet such a demand as might occur on any exploration project. Effort should be made to loose the explorer, or interpreter, from the shackles of too strict routine; thus allowing him to develop greater versatility with which to meet these various problems. We desire that this paper be significant not merely in its approach to the interpretation problem, but that it also serve to embolden interpreters to more effectively utilize the tools available to them.

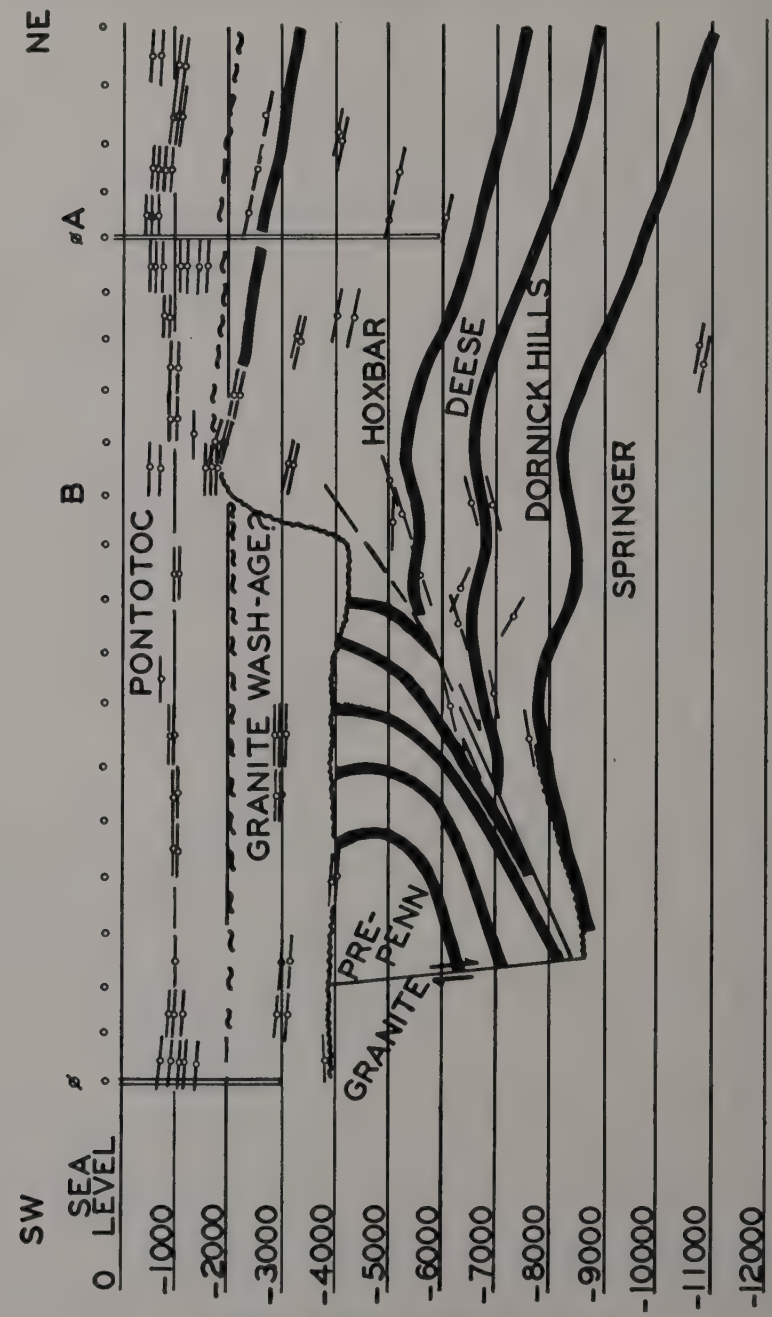


Fig. 4. Interpretation of seismic cross-section SW - NE Line 2.

EXTENSION OF CENTRAL SCHOOL EAST FIELD, LOGAN COUNTY, OKLAHOMA BY GEOLOGICAL AND GEOPHYSICAL COORDINATION

JOHN J. RUPNIK* AND THOMAS E. MATSON*

ABSTRACT

A one-day seismic survey was made in the NW/4 Section 22, Township 17 North, Range 1 East, Logan County, Oklahoma, to evaluate a subsurface structural anomaly. This paper discusses the use of a shallow subsurface, geologic structure map as a reference surface in combination with seismic Viola limestone, unaffected by shallow, near-surface velocity variations. The accuracy requirements for detailed seismic surveying in areas of small anomalies are also discussed.

Introduction

In many areas it has been found that although good seismic reflection records can be obtained and satisfactory weathering corrections can be computed, there are near-surface velocity variables or erratics which cause appreciable "misties" between the seismic horizons and the geologic formations. Usually, the maximum variations occur within the first one or two thousand feet below the surface weathered layer but small variations are frequently present in deeper beds.

The integration of geophysical and geological data is not a new idea, although the procedure described in this article may be slightly different. The method requires adequate subsurface, geological control; this means that relevant wells should have electric logs. Experience has shown that sample logs or driller's logs do not usually provide the precision needed for seismic coordination problems. A shallow geologic reference surface is chosen which is deep enough to eliminate most of the near-surface velocity variables and which will also provide a good seismic reflection. By working with intervals and interval velocities below this plane, structural interpretation of deeper formations usually is more realistic than that provided by conventional seismic structure maps, and depth predictions can be made with greater certainty. The method is not infallible, however, because occasionally there are variables which cannot be controlled. In general, the success of the method depends on:

(1) Accuracy of the seismic picks,

(2) Accuracy of the subsurface data,

(3) Accuracy of the contouring of the shallow subsurface geologic structure map used as the reference surface.

(4) Accuracy of contouring the interval velocity map when sufficient data are available to construct one.

*Manhart, Millison & Beebe, Tulsa, Oklahoma

A Statement of the Geologic and Seismic Problem

The NW/4 Section 22, Township 17 North, Range 1 East, Logan County, Oklahoma, was offered in a proposal which required the drilling of a Second Wilcox sandstone test well. This test well had to be located along the south line of the quarter section to fulfill offset acreage requirements. The proposed location was at the SE SE NW Section 22 (Figure No. 1).

A subsurface geologic structure map contoured on top of the Second Wilcox sandstone in the general area of Section 22, Township 17 North, Range 1 East, accompanied the submittal to support the proposed location. The limited subsurface data had been interpreted to show a structural closure approximately in the N/2 Section 22 which was separate from the Central

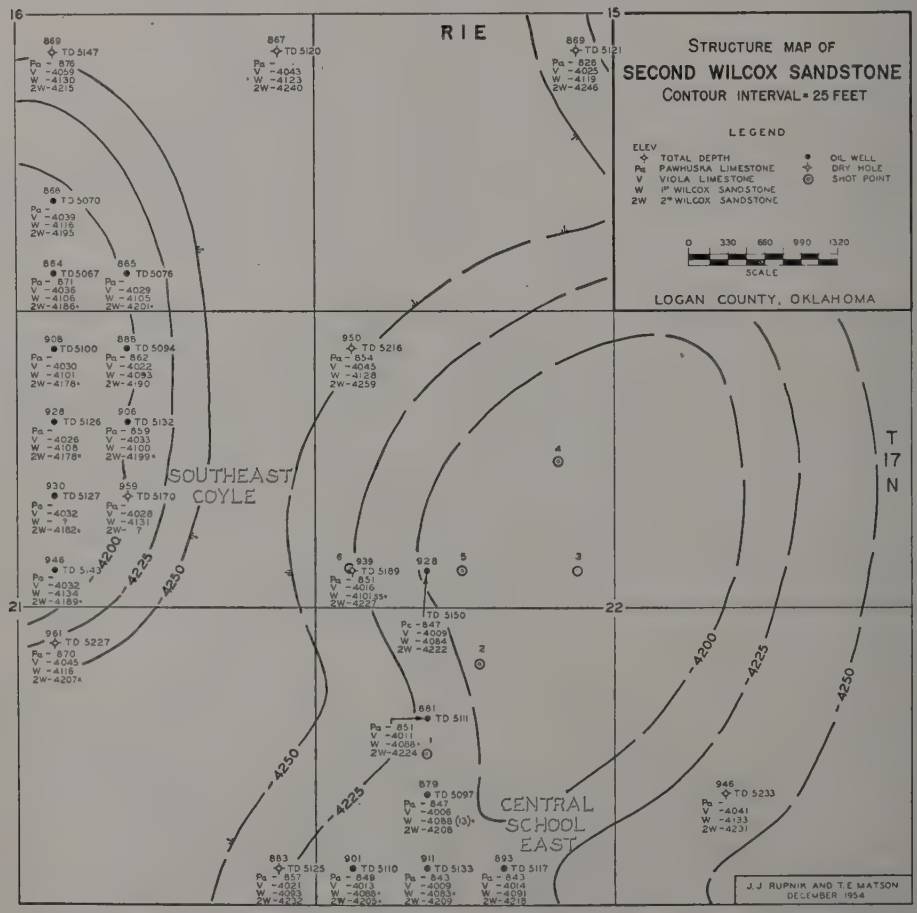


Fig. 1. Subsurface structure map contoured on the Second Wilcox sandstone (original submittal).

School East pool in Sections 22 and 27, Township 17 North, Range 1 East, and also from the SE Coyle pool in Section 21, Township 17 North, Range 1 East.

A subsurface geological study of the SE Coyle and the Central School East pools revealed the following conclusions concerning these pools:

(1) The Pawhuska limestone showed essentially no structural disturbance,

(2) The Viola limestone showed a limited amount of structural relief,

(3) The First Wilcox sandstone, a producing horizon in the area, showed structural conformity with the Viola,

(4) The Second Wilcox sandstone showed marked increase of structural relief compared to the Viola limestone, indicating either pre-Viola structural growth or lateral changes in lithology, or both.

(5) A dry hole in the SW SW NW Section 22, Township 17 North, Range 1 East, had good shows of oil and gas in several sands down to, and including, the First and Second Wilcox sandstones. This well was located on the west flank of the postulated Second Wilcox structure.

Thus it was concluded that if the Viola limestone could be found several feet structurally higher in the proposed test well than at the dry hole at the SW SW NW Section 22, both the First Wilcox sandstone and the Second Wilcox sandstone would be objectives. Therefore, the purpose of the seismic survey was to demonstrate, if possible:

(1) That separate closure did exist on Viola, or pre-Viola formations,

(2) that a drill site location could be made which would be structurally higher on the Viola and Simpson beds than the dry hole at the SW SW NW Section 22 and,

(3) that possible thinning occurred between the Viola limestone and the Second Wilcox sandstone.

To accomplish the above objectives required a precise determination of the structural attitude of the Viola or pre-Viola rocks. An accuracy of plus or minus five feet was believed necessary, therefore, to meet the structural mapping requirements.

Procedure

Following the preliminary examination of the subsurface data, a one-day seismic program was laid out to accomplish the three-fold objective outlined above. Continuous subsurface control was obtained between the network of six shotpoints.

Five maps have been prepared to illustrate the procedure used to evaluate the problem. They are as follows:

(1) The original subsurface geologic structure map contoured on top of the Second Wilcox sandstone,

(2) A conventional seismic time structure map contoured on the Viola limestone,

(3) A seismic map of the time interval between reflections from the Pawhuska limestone and the Viola limestone,

(4) A subsurface geologic structure map contoured on top of the Pawhuska limestone,

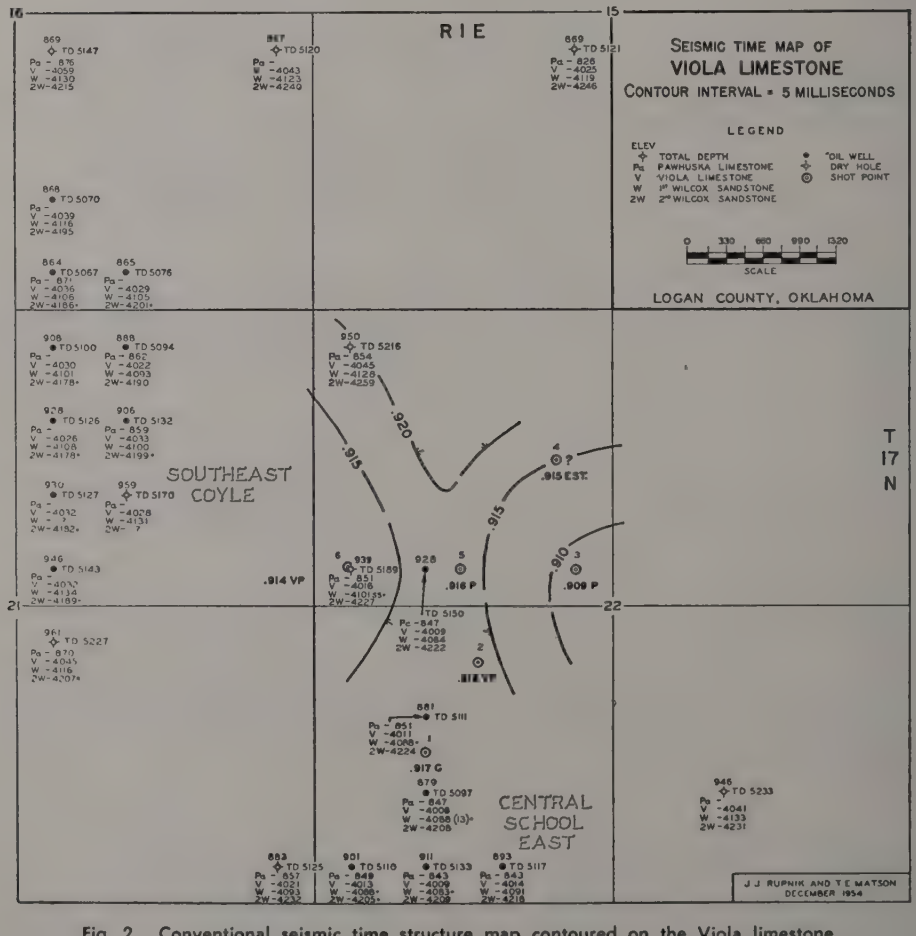


Fig. 2. Conventional seismic time structure map contoured on the Viola limestone.

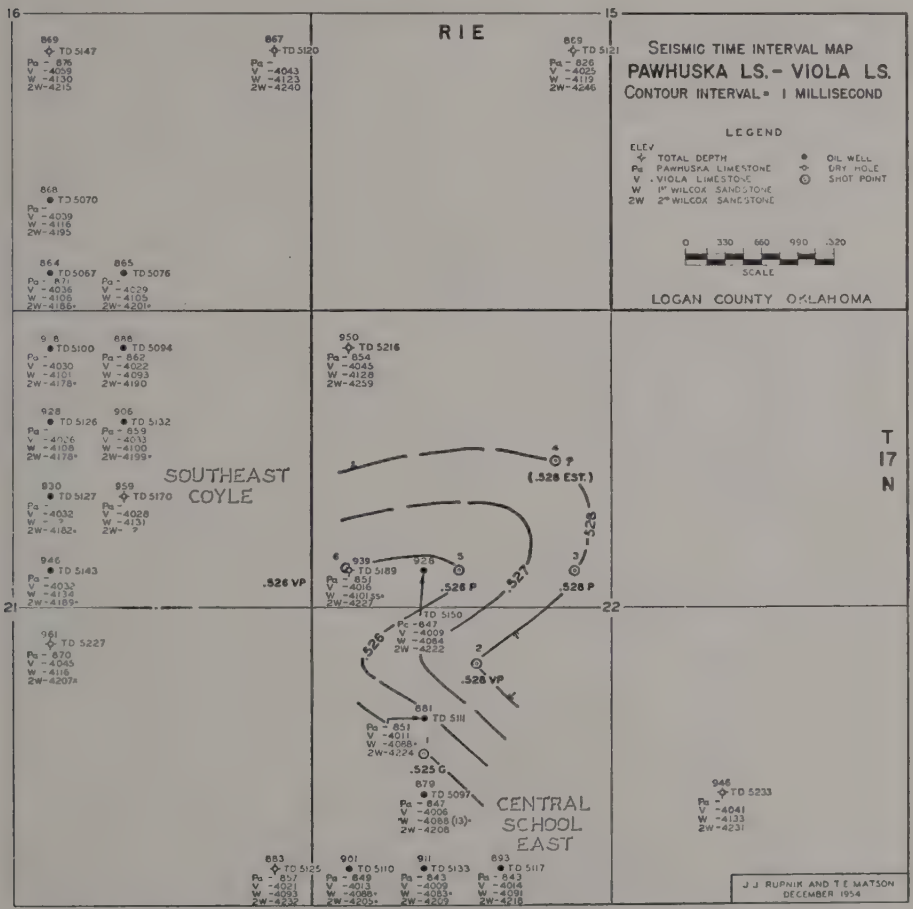


Fig. 3. Seismic time interval map for the interval between the Pawhuska limestone and the Viola limestone.

(5) A subsurface structure map of the Viola limestone based on the integrated geologic and seismic data.

The quality of the seismic data varied from good to very poor. A useable Viola reflection was obtained but deeper data were discontinuous and questionable. At shotpoint No. 4, a Viola time was estimated from a deeper cycle and from the overlying Hunton reflection.

The seismic records were computed using the uphole method of correcting for weathering. It was immediately apparent from the conventional seismic time structure maps that the corrected seismic times between shotpoints Nos. 1 and 6 did not check the subsurface data from the wells. The shallow Pawhuska limestone showed two feet of actual northwest dip where-

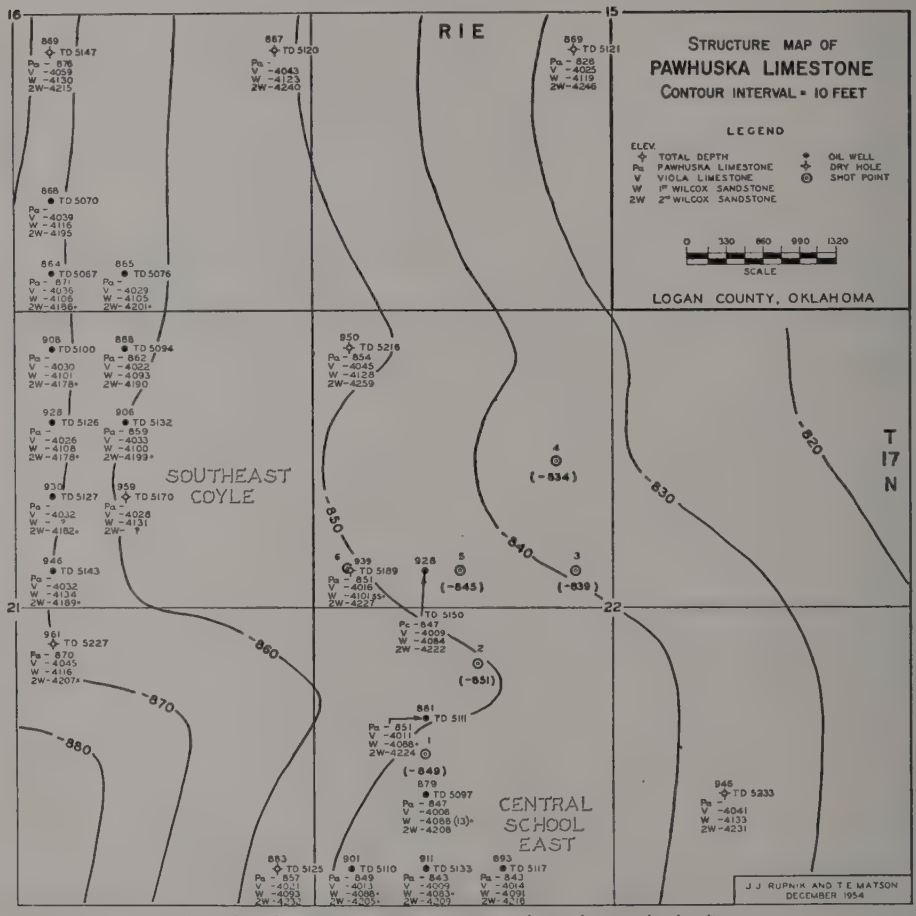


Fig. 4. Subsurface structure map contoured on the Pawhuska limestone.

as the seismic time map of the Pawhuska reflection showed four milliseconds, approximately eighteen feet, of southeast dip. A similar discrepancy was noted for the deeper horizons, including the Viola limestone. The Viola seismic data (Figure No. 2) also indicated that shotpoint No. 3, at the proposed drill site, would be forty to fifty feet structurally higher than the dry hole at shotpoint No. 6. This appeared to be excessive dip.

A further examination of the data revealed that the seismic time intervals and the actual intervals between the Pawhuska limestone and the Viola limestone checked very closely between shotpoints Nos. 1 and 6 (Figure No. 3). consequently, it was decided to integrate the seismic data with the subsurface data by using a subsurface, geologic structural reference surface based on the Pawhuska limestone in combination with the seismic time intervals and interval velocities between the Pawhuska and Viola limestones to obtain an integrated Viola structure map.

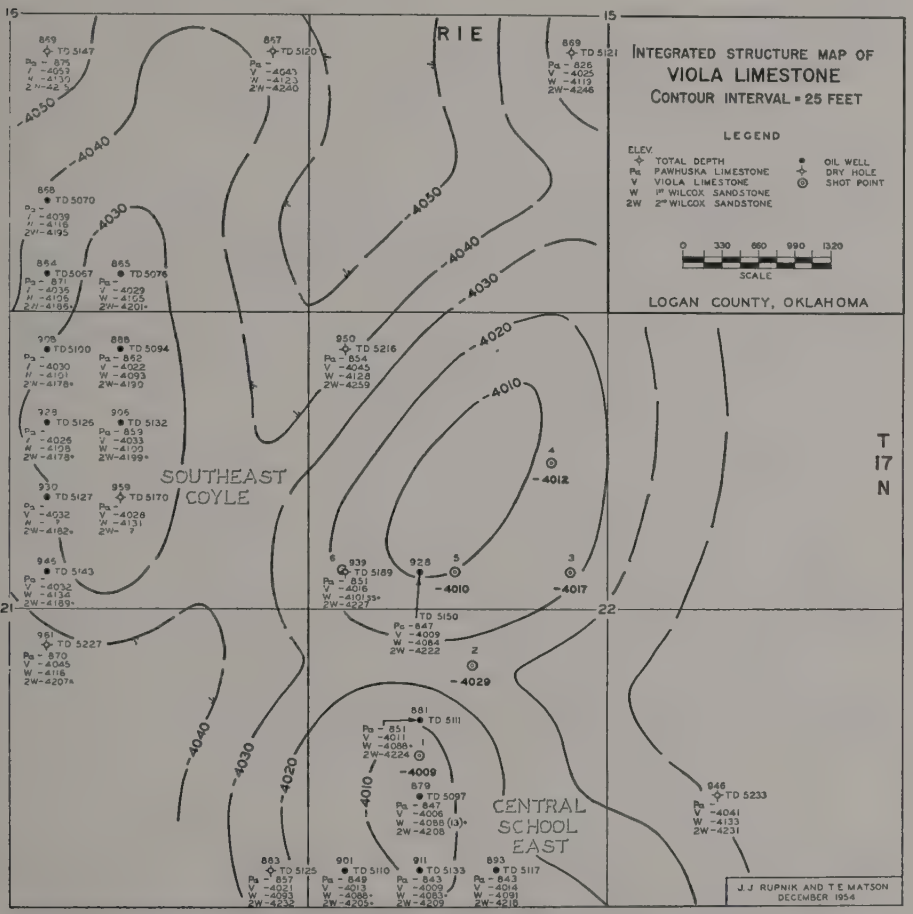


Fig. 5. Structure map of the Viola limestone using the integrated geologic and seismic data.

Step No. 1 consisted of contouring the top of the Pawhuska limestone across the area of interest based on all available electric log control (Figure No. 4). Subsea Pawhuska depths were interpolated at shotpoints Nos. 1 through 5 from this reference plane structure map.

In Step No. 2, interval velocities were computed at the two wells where seismic control was available at shotpoints Nos. 1 and 6. The interval velocity between the Pawhuska and the Viola limestones was 12,038 feet per second at shotpoint No. 1 and it was 12,034 feet per second at shotpoint No. 6. Since no east-west velocity control was available, a constant velocity equal to 12,036 feet per second was used to convert the equivalent time intervals to feet at each shotpoint. It is preferable to have velocity control at more than two wells in a local area to determine if a velocity gradient exists in any direction across the anomalous area. The importance of this control becomes

apparent when it is realized that, for the above conditions, a change of only 20 feet per second in the interval results in a change of thickness equal to five feet.

Step No. 3 consisted of the conversion to feet of the Pawhuska-Viola time interval at each shotpoint using the interval velocity of 12,036 feet per second.

In Step No. 4, the intervals computed in the previous step were added to the respective interpolated Pawhuska subsea depths to obtain a Viola subsea depth at each shotpoint. These depths and those from the subsurface geologic information comprise the data for the final integrated Viola structure map (Figure No. 5).

On the basis of the final Viola structure map, the Josaline Production Company, Baker No. 1 was located at the SE SW NW Section 22, Township 17 North, Range 1 East, and was drilled to the Second Wilcox sandstone. The well was completed for 45 barrels of oil and 43 barrels of water for twelve hours on January 6, 1954, from the First Wilcox sandstone since the Second Wilcox sandstone did not gain additional structure. The final seismic prediction on the structure was that the Viola limestone would be found at minus 4,010 feet at the drill site, or six feet higher than the reference dry hole at the SW SW NW Section 22. The actual Viola top by the electric log was minus 4,009 feet. This method has now been used in six different areas. In four of these, the prediction was within five feet of the actual, drilled-out top.

The originally proposed location at the SE SE SW Section 22 was not regarded as favorable for a drill site because it was shown to be flat with the dry hole at the SW SW NW Section 22 instead of being forty to fifty feet high as shown by the conventional seismic time map.

Conclusions

Two of the three objectives of the seismic survey were accomplished by means of the close geophysical and geological coordination; they were: (1) demonstration of separate structural closure on the Viola limestone and (2), the demonstration of a structurally high location on the Viola limestone as compared to the dry hole at the SW SW NW Section 22. The third objective, which was to map structural thinning below the Viola limestone, was not accomplished because the seismic data were questionable below the Viola limestone.

It is concluded that by close coordination of geology and geophysics, the limits of accuracy of seismic surveying can be reduced considerably in many areas over the presently accepted standard of accuracy, thus making it possible to provide realistic evaluations of structures of small relief.

ACKNOWLEDGEMENT

The writers wish to express appreciation to the Josaline Production Company and to Oklahoma Natural Gas Company for permission to publish this paper, and to Mr. Garth W. Caylor for furnishing much of the geological data.

IMPORTANCE OF GEOLOGICAL STUDIES IN THE INTERPRETATION OF QUANTITATIVE ELECTRIC LOG DETERMINATIONS

R. G. Hamilton*

The Electric Log as an Oil Finder

Improved quantitative relationships makes it possible today to locate oil or gas deposits from the electric log. However, the accuracy of the determinations and the importance of the oil or gas deposits must almost always be evaluated by supplemental geological studies.

Percent porosity may be obtained from normal resistivity curves, the Limestone Curve, the Microlog, the Contact Log, the Microlaterolog and the Neutron Curve. Resistivity methods usually employ the Archie or the Humble equation:

(1) Humble equation: $P\% = 100 \times \left(\frac{0.62}{F}\right) \frac{1}{2.15}$

F is obtained from invaded, short spaced resistivity curves.

(2) Archie equation: $P\% = 100 \times \left(\frac{1}{F}\right) \frac{1}{m}$

m varies from 1.3 to 2.5, depending upon cementation, pore structure and other factors.

Utilizing the Formation Factor, F, thus obtained, the water saturation may be obtained from the generalized equation:

(3) Water saturation: $S\% = 100 \times \left(\frac{Ro = F \times Rw}{Rt}\right) \frac{1}{n}$

n is the saturation coefficient usually about 2.0 but varying with saturation, density of oil and clay mineral content.

Ro is the resistivity of the rock completely saturated with water having a resistivity *Rw*.

Rt is the true resistivity of the rock determined from various resistivity curves.

Accuracy of the water saturation calculated, depends upon the accuracy of the n and m values assumed. These may be measured in the laboratory on cores, but cores are seldom present. They may be approximated by an "experience factor" derived from extensive comparison of laboratory determined numbers with geological, lithological and reservoir data.

Oil or gas may be present but the log analyst may not discover it unless he correctly interprets the log data. Each formation contains water, or oil and water, in varying proportions, and there is a maximum amount of water it can contain and permit the production of oil without water. This maximum amount of connate water is sometimes called the "critical water saturation" or "saturation index" and is expressed as a fraction or percent.

The critical saturations depend upon the densities of the oil and water, relative permeability of the rock to oil and water, pore structure and other

* Hamilton Well Log Consultants; Tulsa, Okla.

factors perhaps not too well known today. Clean sandstones and clastic rocks frequently contain 40% water and yet produce clean oil initially. Shaly and dirty sandstones may contain as much as 60% water and produce clean oil or gas. Limestones and dolomites usually have a much lower "saturation index" and frequently produce some water when the water saturation exceeds 20% to 25%.

The critical values must be learned through experience, by comparison of water data with the results of tests on all formations and rock types. To correctly interpret the electric log derived data with respect to the "critical saturation", the log analyst is interested in answers to the following questions:

Is the rock a limestone or sandstone type?
What is the nature and distribution of the porosity?
Is the calculated porosity total or effective porosity?
What degree of cementation exists?
Is the cementing material calcareous?
Does the sandstone contain numerous, very thin limestone layers?
What is the volume, type and distribution of clay mineral?
Is the formation shaly?
What is the dip of the bed?
Does the sandstone or limestone have "lateral extent" or is it merely a lenticular layer cut by this drill hole?
What is the salinity and density of the connate water?
What is the density of the oil?
What was the drilling time?
Was the formation drill stem tested just prior to logging?
Does the isopach and structural map indicate a "Commercial" reservoir or is this merely a local permeable body that would produce a relatively small amount of fluid?

The astute log analyst will attempt to answer each question before making a final decision to test the formation.

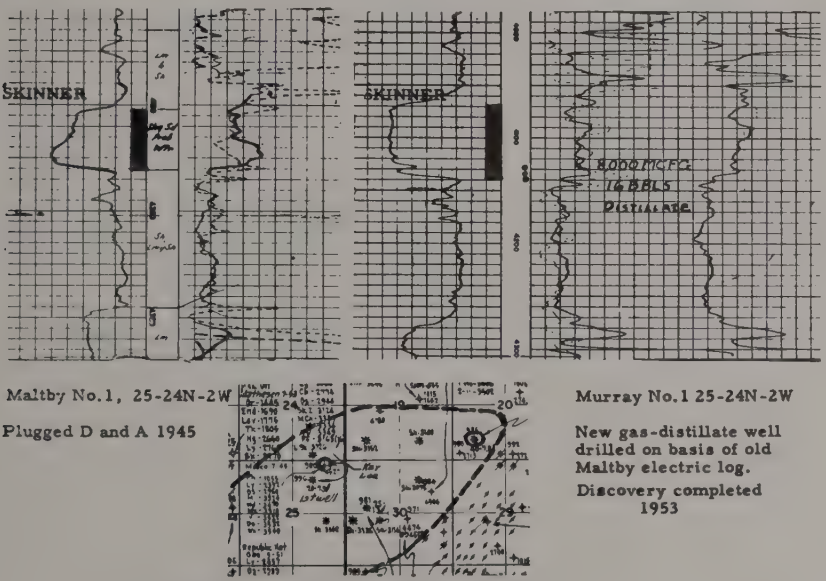
Examples

The writer is aware of at least sixty "dry" holes that were converted into oil or gas producers during the past few years as a result of re-analysis of the old electric logs. In each instance geological studies were essential to the correct interpretation of the log data and for the determination of the commercial aspects of the reservoir formation.

One interesting discovery is illustrated by Figure 1. The Maltby No. 1 well was plugged in 1945 at a total depth of 4522' in the Wilcox sand with no shows being reported in the Skinner sand section. In May 1953, the old log was re-analyzed and the Skinner pronounced as potentially oil productive. Study of this log and all others in the vicinity was supplemented with isopach and structural mapping. The structural sand trap was outlined wherein the thick sand body shaled out up dip to the East as well as to the North and South. Fifty feet of sand existed along the axis running Northeast-Southwest. It was predicted that oil would probably be found on the down dip end if not on the upper part of the sand lense.

The Murray No. 1 well was completed near the Maltby dry hole in July 1953 for an initial production of 8,000,000 cubic feet of gas and about 16 barrels of distillate per day from the lower ten feet of sand. A plugged hole in section 20-24N-1W was then re-opened and completed for gas-distillate, proving the existence of a large gas-distillate sand reservoir. Ten additional gas-distillate wells were drilled in the field and in December 1954, Jernigan and Morgan completed an oil well in the Skinner sand on the down-dip part of the reservoir west of the Maltby No. 1 well. The well flowed eleven barrels of oil per hour with one and one-half million feet of gas.

Table I presents the data derived from some of the electric logs of a few dry holes during the preliminary study:



Well Log	Depth	Total Permeable Sand	Section	Porosity	Water Saturation	Probable Production
Midco Oil Co., Maltby #1, NW NE NE 25-24N-2W	4100-60′	31′		16-18%	25%	Oil or Gas
Mid-Continent Petr. Co., Robertson #1 30-24N-1W	4070-4120′	25′		16-18%	24%	Oil or Gas
Davidor & Davidor, Wilkins #1 30-24N-1W	4064-4113′	8′		16-17%	25-30%	Oil or Gas
Falcon-Seaboard, Finch #1 NE SW SW 20-24N-1W	4085-4132′	30′		16-18%	27%	Oil or Gas

The discovery of this gas-distillate pool is directly attributable to the analysis of the old electric log of a formation that gave no evidence of oil or gas during drilling. The interpretation of the log derived data was supplemented by geological information and geological studies, before a decision was reached to test the Skinner sand. Knowledge of the lithology permitted the correct interpretation of the log data. Geological studies proved the existence of a good commercial prospect.

Conclusions

Broad experience during the past twenty years proves conclusively that the analysis of electric logs and the correct interpretation of the results requires the utilization of lithologic and geological informaion. The analysis of a given electric log may prove the presence of oil or gas in a formation but geological studies are always required to determine the commercial value of the prospect.

ABSTRACTS OF PAPERS AND LECTURES GIVEN BEFORE THE GEOPHYSICAL SOCIETY OF TULSA

A 3-DIMENSIONAL SEISMIC WAVE MODEL WITH BOTH ELECTRICAL AND VISUAL OBSERVATION OF WAVES

J. F. Evans, C. F. Hadley,
J. D. Eisler, and D. Silverman
Stanolind Oil and Gas Company, Tulsa, Oklahoma

October 8, 1953*

The short wave lengths required in a seismic model to give wave-front patterns geometrically similar to those in a large prototype (the earth) can only be obtained by using high frequency sound waves. As sources and detectors of such high frequency waves, piezoelectric crystals are used, primarily because under identical stimuli they are capable of almost perfect duplication. Such duplication is used in displaying on an oscilloscope stationary patterns which are characteristic of transient particle motion at a point in the model. Also, it has made possible the direct visual observation of transient wave fronts in transport models, techniques for which are described, and sample photographs are given. As an example of quantitative use of the described model techniques, the results are presented showing symmetric and anti-symmetric wave propagation in a free elastic plate. Good agreement is found between many features of the experimental record and theoretical predictions. (Authors' Abstract).

*Evans, J. F., Hadley, C. F., Eisler, J. D., Silverman, D., 1954. A three-dimensional seismic wave model with both electrical and visual observation of waves: Geophysics, v. 19, p. 220.

SUMMARY OF THREE YEARS OF SEISMIC FIELD RESEARCH

J. W. Hammond & H. M. Thralls
Seismograph Service Corporation, Tulsa, Oklahoma

November 5, 1953

The operational results and problems of equipping, staffing and administering a seismic crew solely for field research are discussed. A crew designed to meet this demand was activated in August 1950 and has operated continuously on various projects in Oklahoma, Kansas, Texas, Colorado, New Mexico, Nevada, Michigan, Illinois, Louisiana, Georgia, Mississippi, Florida, parts of Canada and Mexico. Objectives were to:

a. Improve general record quality.
b. Develop mappable reflections within a specific geological section.
c. To test record quality and choose field techniques in a completely unknown area.
d. To determine the thickness of the geologic section within an area of no well control.

In operating this crew it was found that the systematic study of test procedures required a sharp change in the attitude of personnel with previous

commercial production experience. Similarly, there was a need to de-emphasize some modern equipment improvements, such as automatic volume control, and to relearn older, discarded, field techniques.

It was found that one month's field work was generally adequate to exhaust the relevant combinations of control conditions at shot point, geophones, and instruments. Little benefit is obtained by continuously extending the study, but new ideas often occur as the data are digested which justify, later, short periods of experimentation.

Equipment used by the experimental crew was described and records shown to illustrate the solution of problems by finding optimum conditions of shot hole depth, charge size, geophone plants and patterns, amplifier frequency response, and A.V.C. control.

A desirable long range goal for the field research crew is the establishment of a diagnostic procedure designed to break down a general record problem into recognizable individual identities. (Editor's abstract).

PROPAGATION OF RADIO FREQUENCY ENERGY THROUGH THE EARTH

F. M. McGehee, jr.

United Gas Corporation, Shreveport, Louisiana

December 10, 1953*

Measurements have been made of some propagation characteristics in the earth of 1,164 and 1,700 kc radio frequency energy. The experiments were conducted at Carlsbad Caverns, New Mexico, and Mammoth Cave, Kentucky. Transmitters were set up on the surface 710 feet above an unwired tunnel in Carlsbad Caverns and the signal strength was measured at many points in the tunnels. A similar series of measurements was made in Mammoth Cave in a tunnel 270 feet below the surface. The data show that the attenuation constant is about 0.012 and 0.02 to 0.064 neper/meter at the two locations respectively. These values are in good agreement with theory. (Author's Abstract).

IMPULSIVE RESPONSE OF A PLANTED GEOPHONE

R. G. Piety

Phillips Petroleum Company, Bartlesville, Oklahoma

January 14, 1954

The interaction between the ground and a geophone is described in terms of the response to an impulsive force acting on the geophone. Experimental observations are shown exhibiting the wide range of variation to be expected in field practice. In general a tightly planted geophone is much more highly

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*McGehee, Jr., F. M., 1954, Propagation of radio frequency energy through the earth: Geophysics, v. 19, p. 459.

damped than a geophone resting on the surface. The impulsive response is obtained by dropping a small steel ball on the planted geophone. By interpreting the time moments of the geophone impulsive response, a differential operator is obtained which expresses the transformation made on the seismic motion of the ground by the plant. It is observed that in some cases the behavior indicates that reciprocity between the reception and transmission of a pair of differently planted geophones holds true. (Author's Abstract)

WAVELET THEORY OF SEISMOGRAM STRUCTURE

Norman Ricker, s.e.g. Distinguished Lecturer

The Carter Oil Company, Tulsa, Oklahoma

January 28, 1954

Dr. Norman Ricker was named distinquished lecturer for the 1953-54 season by the Society of Exploration Geophysicists and under the Society's sponsorship completed a lecture tour taking him to fourteen of the local societies as follows:

November 23, 1953—Ft. Worth Geophysical Society, Fort Worth, Texas
November 24, 1953—Dallas Geophysical Society, Dallas, Texas
November 30, 1953—Ark-La-Tex Geophysical Society, Shreveport, La.
December 1, 1953—Permian Basin Geophysical Society, Midland, Texas
December 8, 1953—Pacific Coast Section, Society of Exploration Geophysicists, Los Angeles, California
December 10, 1953—Canadian Society of Exploration Geophysicists, Calgary, Alberta, Canada
December 14, 1953—Montana Geophysical Society, Billings, Montana
December 15, 1953—Casper Geophysical Society, Casper, Wyoming
December 17, 1953—Dakota Geophysical Society, Bismarck, North Dakota
December 21, 1953—Geophysical Society of Oklahoma City, Okla. City, Okla.
January 11, 1954—Denver Geophysical Society, Denver, Colorado
January 21, 1954—Society of Exploration Geophysicists Houston Texas Section, Houston, Texas
January 28, 1954—Geophysical Society of Tulsa, Tulsa, Oklahoma
March 15, 1954—Southeastern Geophysical Society, New Orleans, La.

Dr. Ricker spoke on "The Wavelet Theory of Seismogram Structure", the lecture being of a survey nature covering his work over about fifteen years. The following gives the substance of Dr. Ricker's lecture.

After demonstrating the failure of the classical elastic solid theory to explain the nature of seismograms satisfactorily it was shown that absorption of high frequency waves could explain the relatively low frequency sinuous motion of the seismograph trace produced by a shot pulse rich in high frequency energy. He showed that the disturbance propagated by the earth had a form determined by the steepness of the edge of the earth's absorption band and that the disturbance broadened as it moved along in such a manner that the breadth of the disturbance was related functionally to the propagation time by a relation also determined by the steepness of the edge of the earth's absorption band. An investigation of the disturbance experimentally, determined the shape of the earth's transmission curve as a function of frequency

for low frequencies and indicated also that at low frequencies there is no appreciable dispersion. It was shown that a wave equation given in 1845 by Sir George Gabriel Stokes propagated waves with just this type of absorption and lack of dispersion at low frequencies. The question then arises, "Does Stokes' wave equation explain the propagation of a seismic disturbance satisfactorily as it moves out from the explosive source". A mathematical investigation showed that a disturbance propagated outward from a sharp explosive source takes the form of what he calls a "seismic wavelet" which changes shape and broadens as it moves outward and decays by an inverse power relationship. A number of laws of wavelet propagation followed from the theory and these laws, together with the predicted shape of the wavelet were then subject to experimental check for verification or refutation.

An extensive series of experimental studies were conducted in the Denver basin in eastern Colorado where the Pierre Shale is exposed at the surface of the ground. At the selected sites this shale is about 4500 feet thick and is sufficiently homogeneous to permit satisfactory research to be conducted in it. As a result of these experimental studies the experimental observations agreed very satisfactorily with the laws of propagation and shape of the disturbance as predicted by the theory, thus establishing the importance of Stokes' Wave Equation in seismic wave propagation.

It was next shown how the theory for a homogeneous earth could be extended into a layered earth. The reflections from a series of reflecting beds produce a series of wavelet forms which may be picked for travel time determinations provided they are not too closely spaced, but if the reflecting beds are close together the wavelets overlap and produce a complicated seismogram. Two or more overlapping wavelets form a "wavelet complex" and a seismogram, free from instrumental distortions, is a very elaborate wavelet complex. Studies of simple wavelet complexes enable calculations to be made of the resolving power of the seismic method and enable a value to be obtained for the closest, two reflecting interfaces can be to one another and still be mapped as separate beds.

It was next brought out that in order to map reflecting surfaces properly the distortions produced by most seismographs must be removed. The discussion then moved into a consideration of the requirements to be imposed upon seismic apparatus for no distortion of the wavelet form. There are two requirements, one relative to the phase characteristic and the other relative to the amplitude response characteristic. In meeting the amplitude response requirement there are three possibilities.

1. A flat response characteristic whereby the wavelet emerges undistorted and of the same breadth as it had upon entering.
2. A rapidly rising characteristic (with respect to frequency) of specific shape, called the wavelet contractor characteristic, in which case the emergent wavelet is undistorted but is contracted to a lesser breadth.
3. A characteristic which falls rapidly with increasing frequency and also of specific shape, called the wavelet expander characteristic, in which case the emergent wavelet is undistorted but is broadened relative to its breadth upon entry.

It was demonstrated that wavelet contraction results in increased sharpness of seismograms, enabling beds to be mapped more closely and enabling pinchouts and truncations to be carried farther than with conventional seismographs. Laboratory studies with wavelet contracting circuits were described and the description of a complete field seismograph utilizing wavelet contraction was given. With this wavelet contracting seismograph a critical field evaluation of the instrument was described and the superiority of the wavelet contractor over conventional seismographs was established in regions where reflections are good by ordinary standards. It was pointed out, however, that the wavelet contractor is not a cure-all for all of our seismic worries and that bad reflections areas constitute another problem.

The application of the theory to reducing distortions in galvanometers and geophones also was discussed. (Author's Abstract)

Ricker, Norman. A Note on the Determination of the Viscosity of Shale from the Measurement of Wavelet Breadth, Geophysics, Vol. VI, No. 3, p. 254 (1941).

_____ The Computation of Output Disturbance from Amplifiers for True Wavelet Inputs, ibid Vol. X, No. 2, p. 207 (1945).

_____ The Form and Nature of Seismic Waves and the Structure of Seismograms, ibid Vol. V, No. 4, p. 348 (1940).

_____ Wavelet Functions and Their Polynomicals, ibid Vol. IX, No. 3, p. 314 (1944).

_____ The Form and Laws of Propagation of Seismic Wavelets, ibid Vol. XVIII, No. 1, p. 10 (1953).

_____ Wavelet Contraction, Wavelet Expansion, and The Control of Seismic Resolution, ibid Vol. XVIII, No. 4, p. 769 (1953).

SYMPOSIUM: IMPROVEMENT OF SEISMIC RESULTS WITH MULTIPLE SHOT HOLES AND GEOPHONES

Ben F. Rummerfield, *Moderator*
Century Geophysical Company, Tulsa, Oklahoma

February 11, 1954*

Questionable reflection seismic results are associated with anomalous surface and near surface velocity variations in West Texas, the Anadarko Basin, Florida, parts of Mississippi, Alabama, Michigan and Canada. Attempts at record improvement have followed the expedient of using deeper holes, study of refraction arrivals, offset or arc or air shooting, and finally pattern holes and multiple geophones.

In general, pattern holes and multiple geophones permit record improvement in marginal reflection areas. The particular technique must be tailored to the area. Usually it is found that:

1. Record quality improves with increase in number of geophones.
2. Shallow pattern shots give better results in areas of high speed surface beds.
3. Deep pattern shots give better results in areas of low speed surface beds.

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*For further review and illustration from this symposium see Oil and Gas Journal, v. 52, No. 50, p. 136 ff, April 19, 1954.

Average cost increase for use of pattern holes and multiple geophones is 25%. (Editor's abstract)

A. E. McKay

*Continental Geophysical Co., Ft. Worth, Texas**

Patterns of shot holes and patterns of seismometers are now standard technique in many areas currently being surveyed by the seismograph. This paper reviews some of these pattern arrangements and shows comparison records in a number of areas such as New Mexico, West Texas, western Oklahoma, Mississippi, and Florida. Although pattern shooting is definitely proven as a useful technique, it is not to be construed as a cure-all for difficult shooting areas. (Author's abstract)

*McKay, A. E., 1954, Review of Pattern Shooting: Geophysics, v. 19, p. 420.

J. A. Smith

Humble Oil & Refining Company, Houston, Ttxas

Specific examples of record improvement with various combinations of multiple shot holes and geophone patterns were presented. (Editor's abstract)

J. W. Hammond

Seismograph Service Corporation, Tulsa, Oklahoma

Interfering ground motion may often be analyzed for apparent velocity and frequency from records obtained on wide-band, flat frequency response, recording systems using dynamite caps or falling weights as an energy source. Spaced geophone arrays may then be designed to amplify certain frequencies and attenuate others, effecting an increase in reflection to noise ratio. With multiple geophones a better average geophone plant is obtained. (Editor's abstract)

F. F. Reynolds

Seismic Exploration, Inc., Houston, Texas

The frequency response of geophone arrays in a linear and star pattern are developed for continuous wave conditions and the affects of geophone number, spacing, and geometry of pattern are studied. (Editor's abstract)

THE EFFECT OF RE-REFLECTIONS ON REFLECTION SEISMOGRAMS

S. E. Giulio

The Carter Oil Company, Tulsa, Oklahoma

March 11, 1954

In seismic reflection shooting, the down-traveling pulse from the shot is reflected from subsurface layers and may be recorded on surface geophone spreads. The up-traveling disturbance is often reflected downward from an interface above the shot to produce a second down-traveling pulse. The reflections of this second pulse from subsurface beds are called "re-reflections". Evidence is presented which shows the existence of the second down-traveling pulse as well as some of its effects on the characteristics of field seismograms. Another purpose of this paper is to explain how to recognize re-reflections and to tell what may be done to minimize their effects.

The existence of a second down-traveling disturbance and its probable effect on the characteristics of seismograms was first noted in the literature by Leet*. Others have also described a downward reflection from above the shot, one of the most recent being Van Melle and Weatherburn**.

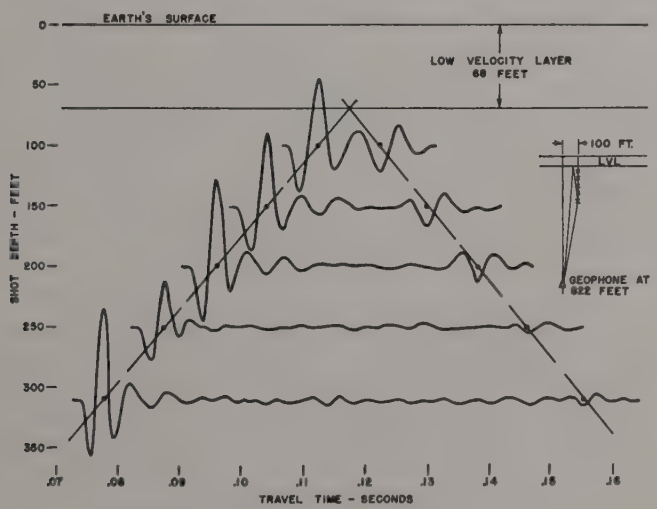

Fig. 1

*Leet, L. Don, "A Plutonic Phase in Seismic Prospecting", Bull. Seis. Society of America, 27, 2, April 1937, p. 97.

**VanMelle, F. A., and Weatherburn, K. R., "Ghost Reflections Caused by Energy Initially Reflected Above the Level of the Shot", Geophysics, Vol. 18, No. 4, October 1953, p. 793.

The principal condition required for the presence of re-reflections is a prominent contrast in acoustic impedance above the shot. This contrast may be, for example, a high or low velocity stringer, but is more often the base of the weathered layer. Given this contrast there are then two types of re-reflection interference which may result. For shallow shots, the second down-traveling pulse follows closely and may overlap the initial down-traveling pulse. This overlap will, of course, change the time picks, shape and duration of the down-traveling pulse. For deeper shots, the second pulse may be well separated from the initial pulse and the resulting re-reflections may then interfere with true reflections from deeper horizons. The interference from shallow shots is called "primary" re-reflection interference and that from deeper shots called "secondary".

When present, the interference caused by re-reflections varies with time on the record. This is because of variations in the number and spacing of reflecting interfaces in the geologic section. With many, closely-spaced reflectors, the re-reflections—regardless of their time separation from their true reflections—affect the time picks, shape and number of cycles of true reflections. With widely-spaced horizons, the re-reflections may even appear as separate reflection events.

The downward reflection from the base of the low velocity layer will be inverted in phase relative to the initial down-traveling disturbance. This has been detected readily on deep hole geophone records. It has been difficult, however, to recognize this inversion in phase of the re-reflection on reflection records. This is probably because of interference from background noise, other extraneous disturbances, and minor reflections. Distortion of the reflection transients by some amplifier filters is another contributing factor to the inability of recognizing re-flections by form or character. The uphole time and low velocity time may be used to compute the time interval to expect between, for example, the valley of a true reflection and the peak of its re-reflection. The time interval is twice the difference between the uphole and low velocity times. Application of the time interval in conjunction with other considerations is useful in identifying re-reflections.

The reflection coefficient at the base of the low velocity layer is frequently quite large. Hence the downward reflection from the low velocity base may be of sizeable amplitude compared to the direct down-traveling disturbance, and in experimental observations has been found to range from one-half to one-fourth as large. In many instances, the re-reflection on a given record would be large enough to override the background noise. In other cases, the re-reflections may be so small as to blend in with the background noise and not be evident as reflection events.

Data relative to the reflection from the base of the low velocity layer was obtained on some deep hole geophone records in eastern Colorado. Calibrated flat-response, fixed-gain amplifiers were used for recording. Traces from several records are reproduced in Fig. 1 together with the configuration of shot and geophone holes. The reflected disturbance appears to be inverted in phase, with the slant lines through the correlatable portions of the disturb-

TRACINGS FROM RECORDS SHOWING
VARIATION IN CHARACTER WITH SHOT DEPTH

12 GEOPHONE AT 1320 FEET SOUTH

Fig. 2

ances intersecting at 68 feet. This depth agrees with the depth of the base of the low velocity layer from refraction profiles. The ratio of amplitudes of the initial disturbance to the reflected disturbance appears to increase with shot depth. This could be expected since the geophone is only 822 feet deep, and for the deeper shots the reflected disturbance has traveled almost twice as far as the initial, with consequent loss in amplitude. For deeper well data the amplitude ratios remain essentially unchanged because the geophone is much deeper and the ratios of the travel paths of the reflected to the initial disturbance are nearly unity regardless of shot depth.

Some data from a surface geophone spread are shown in Fig. 2. The observed reflection time from shot to reflector to geophone is shown at the top of the figure and the shot depth is listed at the right. The vertical spacing of the traces, however, is proportional to the uphole time with the 40, 80, and 150 foot tracings omitted to prevent excessive overlap. True reflections, indicated as A, B, etc., are inclined to the right and re-reflections, A', B', etc, are inclined to the left. A line drawn through a reflection will intersect a line drawn through its re-reflection at about ten feet, the base of the low velocity layer. For a given shot depth, the time interval between a reflection and its re-reflection checks quite well with the computed time intervals listed on the left of the traces.

The two types of re-reflection interference are illustrated in this figure. Primary interference occurs in all identified reflections for shots from 20 to about 150 feet. Secondary interference occurs, for example, between Reflection B and Re-reflection A' at shot depths of 270 to 360 feet. Secondary interference occurs also between Reflection C and Re-reflection B' at shot depths of 180 to 305 feet.

These and other figures presented in the talk of March 11, 1954 show the presence, identification, and some of the effects of the downward reflection from an interface above the shot. A large number of records have been studied and results indicate that the re-reflection occurs on about half the records examined. Obviously, shooting near the base of the low velocity layer appears about the best way of avoiding the effects of re-reflections, provided other conditions will permit shooting at that place. Shooting at an arbitrary depth (say 60 feet) all over an area may be undesirable if the low velocity layer varies from nearly zero to 50 feet. It is clear that exploration people should be aware of the possibility of the occurrence of re-reflections and account for them in both their shooting and interpretation programs.

FILTERING OF SEISMIC ENERGY

Phil P. Gaby

Delta Exploration Company, Jackson, Mississippi

March 11, 1954

An outline review of the problem is given and the chief advantages and disadvantages are pointed out. It is suggested that a wide pass-band with

sharp out-off limits should be most advantageous. Width and position of pass-band should be selected to pass all real components of reflection frequencies.

The problem of "tailing" or "ringing" is considered and experimental evidence is presented to demonstrate that "ringing" is directly related to rejection of component frequencies and not to sharpness of cut-off.

Noise of variable frequency is then superimposed on the pulses and the effectiveness of sharp cut-off and tapered (soft) cut-offs are compared on the basis of Signal/Noise ratio produced. (Author's abstract)

A VOLCANIC CYCLE AS EXHIBITED BY ITALIAN VOLCANOES

F. M. Bullard, A.A.P.G. *Distinquished Lecturer*

University of Texas

April 19, 1954*

The active volcanoes of Italy include Vesuvius, Stromboli, and Vulcano in the Eolian Islands, and Mt. Etna in Sicily. In addition there are numerous recently extinct craters including the famous crater lake areas in the vicinity of Rome and the Phlegreen Fields in the Naples area. All of these volcanic centers are related to movements which resulted in the uplift of the Apennine Mountains and the subsidence of the Tyrrhenian sea in late Pliocene time.

The activity, which began at the north and gradually shifted southward, is continuing today only in the active volcanoes mentioned above.

It has long been believed that volcanic eruptions, like the weather, exhibit a cyclic pattern and that if this pattern is known, the prediction of the course of a volcanic eruption is possible. Various attempts have been made to work out the pattern of behavior of numerous volcanoes with widely diverging results. Such a variety of factors combine to determine the eruptive character of a volcano that no two volcanoes would be expected to follow the same plan. Continuous observations over long periods of time are a prerequisite for studies of this nature. Such observations are generally lacking. It is perhaps significant that the eruptive pattern is better known on Vesuvius than on any other volcano and it is also perhaps significant that Vesuvius is the best known volcano. It seems profitable to review the eruptive pattern of Vesuvius and to try to evaluate some of the factors which combine to determine the pattern of the eruptive cycle. While other volcanoes would not be expected to follow the same pattern, doubtless such a study will be of tremendous aid in the investigation of the less well known volcanic regions.

The eruptive cycle of Vesuvius is, in general, about 40 years. After a grand eruption, marking the close of a cycle, the new period is initiated by a repose period averaging 3.5 years. This is followed by mild explosive activity in which the upper part of the cone (usually destroyed by the grand

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*Bullard, F. M., "A Volcanic Cycle as Exhibited by Italian Volcanoes, Tulsa Geol Soc. Digest, v. 22, p. 101 (1954).

eruption) is rebuilt and many small (slow) lava flows appear in the crater or emerge on the sides of the cone from cracks in the upper part of the rim. The cycle is brought to a close by the grand eruption in which rapid and large streams of lava issue from fissure on the lower part of the cone followed by tremendous explosions which usually destroy the upper part of the cone. The volcano then lapses into a repose period which marks the beginning of a new cycle.

In comparison, Mt. Etna has a much shorter period, averaging only about 3.5 years between eruptions, but the character of the eruption is quite different. Stromboli, on the other hand is in a continuous state of mild activity, although it is believed that the violent eruptions which are superimposed on the normal activity follow a definite rhythm.

The paper was illustrated with kodachrome slides and color movies, taken by the author during his recent study of the volcanoes of Italy. (Authors abstract)

GEOPHYSICAL TOOLS AND TECHNIQUES FOR URANIUM PROSPECTING

Frank W. Stead

U. S. Geological Survey

May 13, 1954*

Uranium and thorium ores because of their radioactivity allow a direct method of geophysical exploration using portable detection equipment. Other geophysical techniques may indirectly assist the discovery of ore bodies. The development of instruments and techniques for uranium prospecting has been undertaken by the U. S. Geological Survey on behalf of the U. S. Atomic Energy Commission.

Portable Equipment

The most significant development of the last few years has been the portable scintillation counter and its application to field measurements of radioactivity. The efficiency of gamma-ray detection of the scintillation counter is roughly fifty-fold greater than that of the Geiger counter. In prospecting, where searching for relatively small-area, low-grade materials, this increased efficiency of measurement is a significant factor in increasing the rate at which radioactivity surveys can be undertaken. Close-spaced radioactivity surveys have in some areas outlined all known uranium deposits within the isoradioactivity contour representing approximately twice the normal background radiation; such surveys provide supplemental guidance in exploration.

Carbone radioactivity surveys, using scintillation counter installations of the continuously recording type, have been used most effectively in exploring large areas around known uranium deposits and in obtaining regional data for appraising the geologic favorability of an area.

*Oral presentation based on "The Geological Survey's Work on Development of Prospecting Tools, Instruments, and Techniques", Frank W. Stead, U. S. G. S. Trace Elements Investigations Report 211, May 1952.

Gamma-ray Logging

The objective has been to calibrate gamma-ray measurements in terms of the equivalent uranium content and the thickness of uranium ores penetrated by small-diameter drill holes. Simulated drill holes containing carefully measured thicknesses and grades of uranium ores have been used as calibration standards; this approach has led to a calibration chart which, from the practical viewpoint, is reasonably satisfactory where core recovery is poor or lacking. Gamma-ray logging data can now be used for quantitative estimates of grade and thickness. The agreement in thickness between core assay data and the gamma-ray data is good; the agreement in grade between core and gamma-ray data is occasionally unsatisfactory with the grade based on gamma-ray measurements tending to be higher than core assay data by as much as a factor of two.

Airborne Radioactivity Surveying

The objective is to locate large and new areas in which radioactive ores may occur. Such surveying is a reconnaissance tool; it is best applied to areas of at least 50 square miles; and, it demands for guidance the best possible geologic inferences as to where uranium and thorium are most likely to occur. Currently, Douglas DC-3 aircraft are used to obtain long-range operation and relative safety at low flight levels. The full installation for radioactivity surveying consists of 1) the scintillation detection equipment designed and constructed by the Oak Ridge National Laboratory, 2) a recording radar altimeter, and 3) a gyrostabilized continuous-strip-film camera; the total weight of the installation is about 800 pounds. All instruments are interlocked to provide a continuous three-dimensional position of the radioactivity measurements in respect to the ground.

The scintillation detection equipment consists of 1) the amplifier, essentially a straight forward counting rate meter, and 2) six 4-inch diameter by 2-inch-thick NaI crystals. The counting rate of the six crystals at ground level is about 2,000 counts/second. The cosmic ray response of the scintillation equipment increases slowly with increasing altitude, and within the altitude variation of a reconnaissance survey can be considered a constant.

The net response, or total-minus-cosmic, from a broad flat source area selected for uniform radioactivity plots as/a straight line on semi-log scale; the function can be simply expressed as e^{-uh} where u is the absorption coefficient of air and h is the distance above ground. The net response from a point source of radiation can be simply expressed as $e^{-uh/h}$ where the intensity varies with the inverse first power, not with the inverse square of distance from the source.

All measurements in reconnaissance surveying are made at the 500-foot flight level and at 1/4-mile spacing of flight lines to obtain as wide a belt of coverage as the present sensitivity of measurement will permit. Comparison between the results of airborne and ground radioactivity surveys demonstrates that with very few exceptions the airborne measurements either confirm previously known high radioactivity or are themselves confirmed by later ground examination. (Editor's abstract)

CONSTITUTION AND BY-LAWS

(*As amended to November* 13, 1952)

ARTICLE I

NAME

The name of this Society is the *Geophysical Society of Tulsa.* It shall be the Tulsa Section of the Society of Exploration Geophysicists.

ARTICLE II

OBJECT

The object of this Society is to promote the science of geophysics especially as it applies to exploration, and to promote fellowship and cooperation among those persons interested in geophysical problems.

ARTICLE III

MEMBERSHIP

1. Any person interested in the geophysical profession shall be eligible for membership.
2. Applications for membership shall be submitted in writing, and shall be signed by three sponsors who are members of the Society.
3. Applications shall be approved for membership by the Executive Committee.
4. The annual dues of members of the Society shall be three dollars ($3.00) payable in advance on the first day of each calendar year.
5. Members whose applications are approved after July 1 shall be required to pay only one-half the regular annual dues for the remainder of the first year of their membership.
6. Charter Members of this Society will be those who attended the first organizational meeting of the Society on February 4, 1947, or who attended the second meeting on March 13, 1947, and signed the respective roll as charter members, and who have paid dues for the year 1947.

ARTICLE IV

RESIGNATION AND SUSPENSION

1. Any member may resign from the Society at any time. Such Resignation shall be in writing and shall be accepted by the Executive Committee, subject to the payment of all outstanding dues and obligations of the resigning member.

Note: The Constitution was originally adopted March 13, 1947. It was amended January 8, 1948, November 11, 1948, February 9, 1950, and November 13, 1952. The By-Laws were amended February 9, 1950, and November 13, 1952. The editor is very much indebted to Paul L. Lyons for his assistance in writing and editing this revision of the Constitution.

2. Any member who is more than one year delinquent in payment of dues shall be suspended from the Society. Any delinquent or suspended member, at his own option, may request in writing that he be dropped from the Society and such request shall be granted by the Executive Committee after due notification. Any member more than two years in arrears shall be dropped from the Society.
3. Any person who has ceased to be a member under Section 1 or Section 2 of the Article may be reinstated by unanimous vote of the Executive Committee subject to the payment of any outstanding dues and obligations which were incurred prior to the date when he ceased to be a member of the Society.

ARTICLE V

OFFICERS AND THEIR DUTIES

1. The officers of the Society shall be: President, First Vice-President, Second Vice-President, Secretary, Treasurer, and Editor.
2. There shall be district representatives to the Society of Exploration Geophysicists, as provided in the constitution of that society.
3. The Executive Committee shall consist of the Officers, the two most recent available past presidents, and the district representative, or representatives, to the Society of Exploration Geophysicists.
4. The Officers shall be elected by a ballot as hereinafter provided at the Annual Meeting, and shall hold office for one year.
5. The President shall preside at the meetings of the Society and of the Executive Committee. He shall call special meetings when deemed advisable; shall appoint all committees except as otherwise herein provided; and, jointly with the Secretary-Treasurer, shall sign all written contracts and other obligations of the Society. In the temporary absence of other Officers, he shall assume their duties or delegate them.
6. The First Vice-President shall be responsible for arranging the technical program of the Society, and shall have authority to appoint such assistants as he may require. He shall perform the duties of President in the absence or disability of that Officer, and in case of the President's resignation shall become President for the remainder of the term.
7. The Second Vice-President shall be responsible for arranging entertainment, and shall have power to appoint members to assist him.
8. The Secretary shall maintain a complete list of the membership of the Society and of its Executive Committee, shall mail advance notice of meetings to all members, shall keep minutes of meetings of the Society, and of its Executive Committee, shall notify the members by mail of proposed amendments to the Constitution, and shall mail and receive ballots.

   The Secretary shall submit to the Secretary-Treasurer of the Society of Exploration Geophysicists a report of each meeting of this Society and of its Executive Committee within two weeks following each such meeting. He shall also submit to the Secretary-Treasurer of the Society

of Exploration Geophysicists the names of all Officers and Committee members within two weeks after their election or appointment.

9. The Treasurer shall collect all dues and other obligations to the Society, shall make disbursements authorized by the Executive Committee and shall transact such other business as may be authorized by the Executive Committee. He shall maintain a chronological record of all receipts and expenditures as well as a system of records explaining each expenditure, including evidence of authority to expend funds and evidence of payment. He shall report the condition of the Treasury at each Annual Meeting and at other times upon request of the Executive Committee.

   When so instructed by the Executive Committee, he shall make application to the Secretary-Treasurer of the Society of Exploration Geophysicists for such portion of the expenses to be borne by that Society, as may be needed, and shall submit to the Secretary-Treasurer of the Society of Exploration Geophysicists, prior to the annual meeting of that Society, an itemized account of the expenditure of such funds as may have been received from the Society of Exploration Geophysicists during the preceding calendar year.

   A quorum of the Executive Committee shall consist of at least four members and approval by at least four members will be necessary to conduct all business of the Society.

10. The Editor shall be in charge of the editorial business, shall submit an annual report of such business, shall have authority to solicit papers and material for the regular society publication and for special publications, and may accept or reject material offered for publication. He may appoint editorial assistants.

11. The Executive Committee shall transact all business of the Society not otherwise herein specifically provided for. It shall elect all members to the Society, shall authorize all expenditures, shall direct investments of Society funds, shall establish and supervise publications; shall approve and recommend all proposals for special assessments; shall fill vacancies occurring in any office except in the office of President, to which the First Vice-President automatically succeeds, and shall have the power to review all actions and appointments by the Officers.

12. The District Representatives of the Society of Exploration Geophysicists shall represent the Society and its members at meetings of the Council of the Society of Exploration Geophysicists.

ARTICLE VI

ELECTION OF OFFICERS

1. A slate of nominations for officers shall be prepared by a Committee of Nominations consisting of the President and the two most recent available Past Presidents. They must secure the consent of all candidates nominated. This slate, of two or more candidates for each office, shall be prepared and announced to the Society at its regular meeting in March of each year.

Additional nominations for each office may be made by written petition of ten or more members in good standing. Such nominations must be submitted to the President not later than the close of the regular meeting in April.

The election of officers shall be by secret mail ballot. The Secretary shall mail to all members, not later than three weeks preceding the Annual Meeting, a ballot listing all candidates properly nominated for each office. Each member voting shall cast one vote for each officer and shall return his ballot to the Secretary in a sealed envelope carrying on the outside his written signature. Only ballots so prepared by members in good standing and received by the secretary by 4 P.M. on the Monday immediately preceding the Annual Meeting shall be valid.

The Secretary shall indicate which ballots are valid and shall deliver them unopened to the Committee on Nominations. The Committee on Nominations shall supervise the counting of ballots prior to the Annual Meeting. The candidates receiving the greatest number of votes cast for an office shall be declared elected to that office. In case of a tie, the Executive Committee shall decide which of the tied candidates shall be elected.

2. The Committee on Nominations shall prepare a slate of nominations for any posts of district representatives to the Society of Exploration Geophysicists, which may need to be filled. Additional nominations may be made in the manner set forth in Section 1. The election shall be by secret ballot at least three weeks prior to the annual meeting of the Society of Exploration Geophysicists.

ARTICLE VII

MEETING

1. The Annual Meeting shall be held in May of each year, and shall be held on the second Thursday of May, unless otherwise specified by the Executive Committee and due notice given to the membership.
2. The Regular meetings of the Society shall be held on the second Thursday of each month except during the months of June, July, and August, unless otherwise provided by the Executive Committee.
3. Special meetings may be called at any time by the President of the Society.
4. The time and place of regular meetings, the nature of the technical program and the entertainment, shall be determined by the Executive Committee.

ARTICLE VIII

AMENDMENTS

1. This constitution may be amended by a three-fourths vote of the members present at any regular meeting, provided that the proposed amendment has been approved for submittal by the Executive

Committee and has been moved at a regular meeting previous to the meeting at which the ballot shall be taken.

2. By-laws may be changed by majority vote of members present at any regular monthly meeting.
3. Nothing in this Constitution or By-laws shall be inconsistent with the Constitution and By-laws of the Society of Exploration Geophysicists.

BY-LAWS

I. The Officers and the Executive Committee may arrange for the affiliation with other duly organized groups or societies which by object, aims, constitution or practice are aiding, assisting, or developing the profession of geophysics or allied technology.

II. Until such time as a sufficient number of qualified past Presidents has been created, so as to provide those members necessary to serve on the Executive Committee as provided in the constitution, these Executive Committee members shall be chosen by the Society by a majority vote from open nominations at the Annual Meeting.

III. Prior to the Annual meeting the Treasurer shall close his accounts and submit them to a Committee of three members of the Executive Committee designated by the President. These members shall audit the accounts and then certify their correctness by signing an entry in the cash book.

The new Treasurer shall accept the Society Funds by signing an entry to that effect in the cash book.

IV. The Society shall publish a journal. The journal shall be published at intervals designated by the Executive Committee. All reports to the Society by its officers and committees may be published in the journal. Each issue shall contain a membership list. Each issue shall list all committees. Original papers, reviews, abstracts, notes or information deemed by the Editor to be of interest to the members of the Society shall be published in the journal. The editor shall be sole judge of whether such material is to be published. The executive committee may authorize the printing of the journal and may authorize financing and distribution of the journal.

V. The first editor may be elected at a regular session of the Society following passage of this by-law at a regular meeting.

RULES FOR THE ADMITTANCE OF NEW MEMBERS

1. Any member interested in the Geophysical profession shall be eligible for membership in the Geophysical Society of Tulsa.
2. Applications for membership shall be submitted in writing, and shall be signed by three sponsors who are members of the Society.
3. Applications shall be approved for membership by the Executive Committee.

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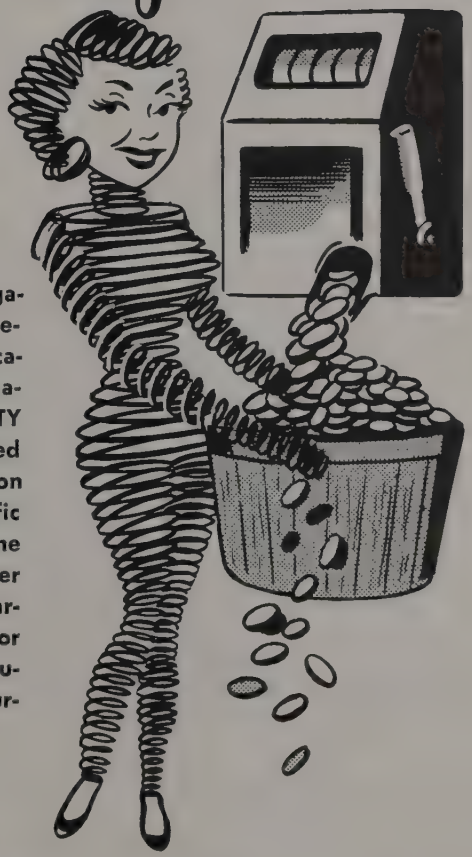

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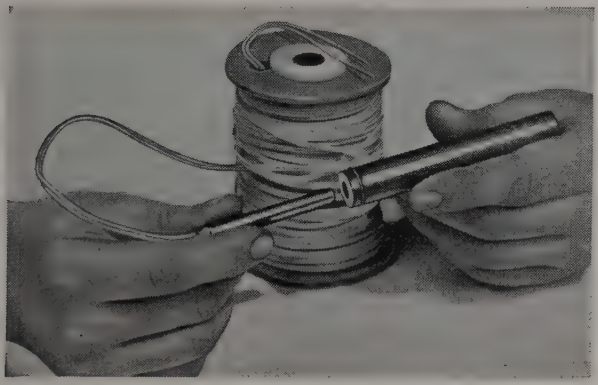

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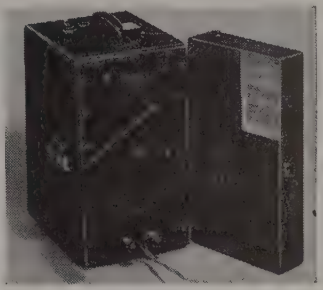

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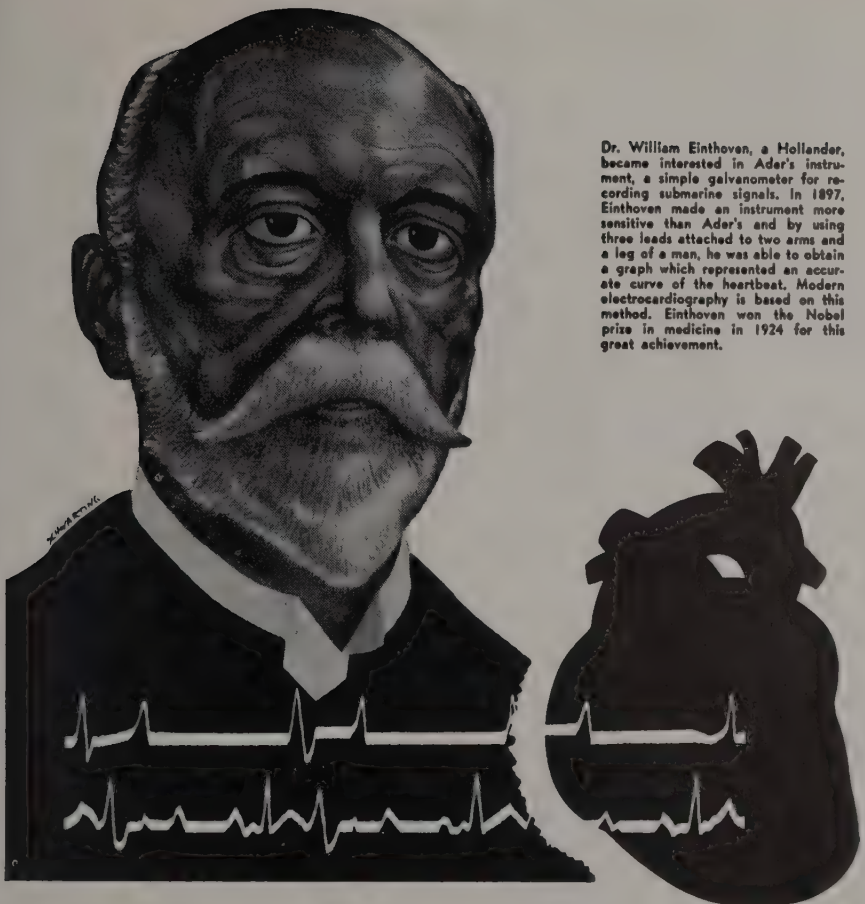

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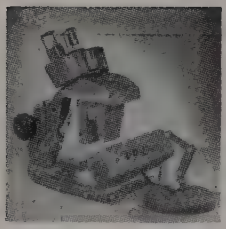

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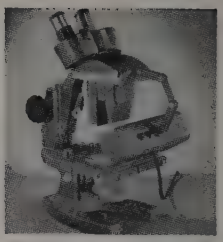

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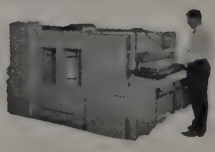

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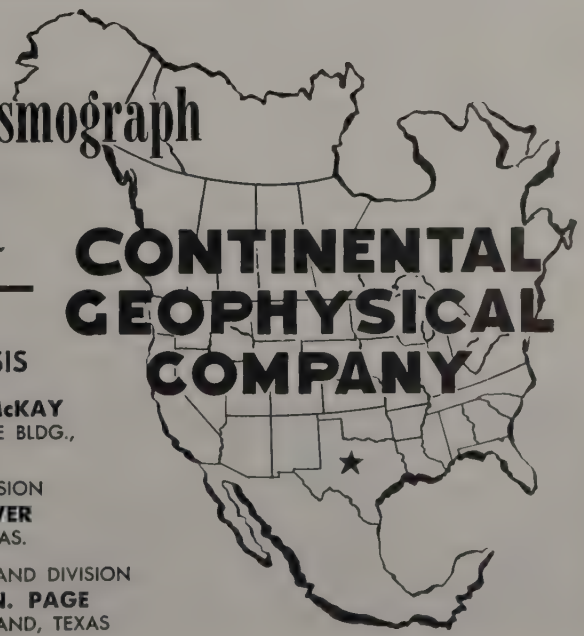

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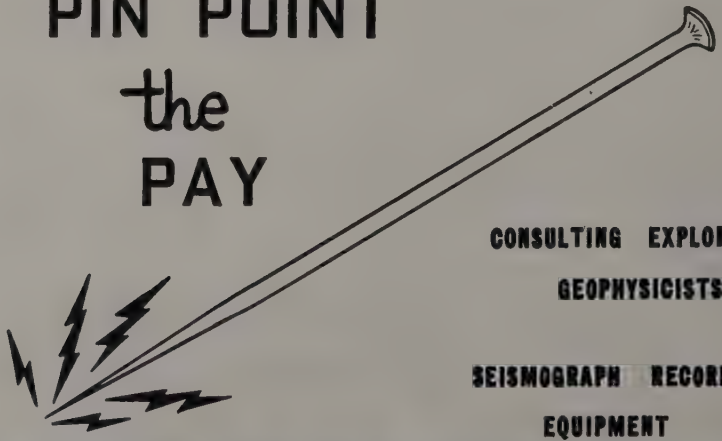

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